RAILWAY TUNNELLING

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BY

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PREFACE.

THIS book, or treatise on Tunnelling, is not supposed by the author to contain anything new or unknown to Engineers or Contractors generally, nor does it contain formulæ or positive rules for constructing such works, as none can be laid down, no two Tunnels ever being exactly similar in conditions affecting their construction. The author believes, however, that his practice and experience as a Civil Engineer and Contractor will enable him to give such information to assistant Engineers and Contractors' assistants as will materially help them, and by describing the general methods and requirements to be adopted in commencing and carrying out Tunnel works, place young Engineers, who may not have much experience in this class of work, in a position to understand what is wanted or what is going on, when called upon to commence a Tunnel, or to take charge of and superintend the works of one already commenced; and so that they may not become tools in the hands of the foreman miner or bricklayer, who in many cases have the work let to them by sub-contract, and who will immediately take advantage of inexperience, to the detriment of the work, disgrace to the management, and loss to the chief Contractor and all concerned in the well-being of the line of Railway.

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CHAPTER I.

LIGHT AND HEAVY GROUND.

TUNNELS are works to be sparingly used in the construction of railways: they require great care and honest work in construction, any giving way causing great expense and delay to traffic while undergoing repair.

A Tunnel, well and carefully constructed, will last for many years without repair, so one of the first considerations is to ensure good superintendence of the works while in progress.

There are cases where they must be introduced. In England all the main lines, and most branch lines, may now be considered as made, and the best and easiest *routes* for them to have been selected, so that any branch or link now to be made will generally have to pass through a rough and difficult country, probably necessitating Tunnelling.

When a cutting attains 70 feet in depth, it is generally advisable to introduce a length of Tunnel. A cutting of this depth, for a double line of rails, with 27 feet width at formation and $1\frac{1}{2}$ to 1 slopes, contains about 1027 cubic yards of excavation per yard forward, which, at 1*s.* 3*d.* per cubic yard, would cost

£64 4*s*., a sum larger than that for which the generality of Tunnels in sound ground could be constructed; again, in many cases, though a cutting would perhaps be preferable, there is no room for depositing the material from the excavation, so a Tunnel is unavoidable; again, sometimes, especially in the present day, a line may be laid out to traverse a valuable estate, and coming upon the spur of a hill, could with ease contour it, but the owner of the estate will not allow an open cutting in his domain, and says that unless the line is carried through the hill by a Tunnel, he will oppose the Bill for the Railway in Parliament, so that very often a Tunnel becomes a necessity and is constructed, where it is obvious the line could have skirted the hill at a comparatively small expense.

It will be seen, therefore, that Tunnelling is in some cases the cheaper, and in others a necessary work.

A Tunnel in sound rock, requiring no lining, is a simple work, but not very often met with in this country, therefore in this treatise it will not be considered; but Tunnels in unsound ground, requiring a lining, are works of a different nature and sometimes very troublesome, especially where the height to the surface of ground over the Tunnel is small.

It may be generally accepted as a fact that the greater the distance between the surface of the ground and the top of the Tunnel, the lighter will the ground be, and the Tunnel consequently easier of construction.

The cause or reason for this apparent anomaly is that in the case of a short distance to the surface, the mining operations cause the whole of the intervening ground to be disturbed, so much so that trees are often shifted in position, and great cracks or fissures appear upon the surface, and the whole weight of the superincumbent earth has to be borne on the timber and lining, and this condition of things is called "heavy ground." When, however, the distance to the surface over the Tunnel is great, the disturbance caused by mining is arrested before it comes to the said surface, and the weight is in a great measure borne in the ground itself, and

does not come upon the bars or lining, but is so to speak "keyed in," and the ground will be what is called "light." With a depth from the surface to the Tunnel top of 50 feet or less, heavy ground may be looked for, unless the geological formation is a strong one.

Before commencing mining operations for getting in a "length" of lining, the general strata of the ground and the direction of their dip should be carefully studied, so that the probable weight to be encountered, and the direction of the probable pressure (whether excessive or otherwise), may be ascertained. The process of sinking the working shafts and of driving the headings, will afford facilities for such examinations; very often, however, no reliable estimate can be made, especially where in a rock formation great disturbance has taken place in the strata: for instance, in some districts, notably Yorkshire, "clay backs" exist between the faults in the rock, the stone has been upheaved and broken into enormous wedges, the sides of which form a zigzag line vertical to the line of the Tunnel, the apices of these wedges being alternately up and down, or above and below the Tunnel; a glance at the section (Fig. 1) will better explain this condition. Water having run between the sides of these wedges has deposited clay, which in process of time has been washed quite clean, and has become as slippery and greasy as soap. In sinking the shafts, driving the headings, etc., this formation may escape observation, and mining for a length of brickwork is commenced; this first length may chance to be driven through one of these wedges with its apex downwards, two, perhaps three, lengths may be got in, and this wedge is cut through, and no great weight been encountered because the wedge pointing downwards tends to support itself; but on a fourth length being essayed in the next wedge with its apex upwards, a great weight is suddenly brought upon the timber, caused by the wedge of rock having its base cut away and sliding down between its clay sides; this weight may be so great that it becomes evident that stronger timber and an increased thickness of lining will be necessary to withstand it.

Among the best and most reliable strata through which a Tunnel requiring a lining can be driven, is shale, provided that the top of the tunnel is not at a higher level than or through the top bed of this formation. Shale is in many instances overlaid by a bed of rock, not, perhaps, of any great thickness; now, in sinking the shafts, a bed of rock may be found a few feet thick, and under it a good shale, the top of this rock being just about at the level of the extrados of the proposed Tunnel arch; if this rock should be found to run nearly level (which can be assumed if found in relatively the same position in the several shafts), it will be better to lower the formation level of the Tunnel a little, so that this bed of rock may not be cut entirely through in the mining operations, for as a rule, if the extrados of the brickwork is under this bed, or only a little way into it, the ground will be light, but if the extrados is above this seam, or if it has to be cut entirely through in the mining, the weight will at once increase, and perhaps become excessive.

An example of this very lately came under the author's observation. A Tunnel was being constructed through shale, with a bed of rock 8 feet thick lying immediately above it and above the arch of the Tunnel; while this condition of the strata existed the weight was not severe, and a thickness of lining of 2 feet 3 inches was amply sufficient; a fault in the strata, however, occurred, and the rock bed was found to be just its own thickness lower in level on the other side of the fault, necessitating its being cut entirely through to get in the above-stated thickness of lining; another length was attempted under this altered condition of the strata, using the same timber as previously, but it soon became evident that the weight was too great—the timber began to fail—so the length had to be shortened and an extra 13½ inches added to the lining.

Clay is not a desirable substance to tunnel through, however sound and good it may appear: water and air have a great effect upon it—the former melts and wastes it away from behind

the timber, causing it (the timber) to give—and the air makes it swell, crushing and breaking the timber employed.

It must be borne in mind by the reader that in this treatise a heavy Tunnel is under consideration—that is, a Tunnel requiring large timber and a thick lining to withstand the superincumbent weight—and one in which the thickness of lining cannot well be, or is not, determined until the work has been partially opened out. In a light Tunnel the same process as is hereinafter explained must be gone through, though in a modified form.

The reason for thus early mentioning "weight," and the uncertainty attending any calculations of the same, will be demonstrated to the reader when he comes to the Chapter treating on "Headings."

CHAPTER II.

ON SINKING WORKING SHAFTS.

A Tunnel having been determined upon, the centre line of it must be very carefully set out over the hill under which the Tunnel is to be constructed, and the first work to be commenced is that of sinking the working shafts. It is not always necessary that any permanent shaft should be constructed; if, however, the Tunnel is over 700 yards long, one permanent shaft may be required, if there is a likelihood of much traffic through the Tunnel, the shaft being useful to let the steam out and for ventilation. In a wet Tunnel, the steam from the locomotives passing through, hangs about for a long time, and is very disagreeable to platelayers who may be repairing the permanent way; and if an engine passing through leaves the Tunnel full of steam, the engine driver of the next entering train will be unable to see his signals, should there be any at the opposite end of the Tunnel to that at which his train entered, which is often the case.

We may take it that the shafts, now to be spoken of, are only for the temporary purposes of the Contractor, to be filled up again when not longer required.

For sinking and lining permanent shafts, the reader is referred to Mr. Sims' work on "Practical Tunnelling," in which they are fully and clearly described, as are also many other details, which will be found very useful; but the author ventures to think that Mr. Sims, though describing much with great and careful detail, has rather hurried over his explanations of mining operations.

This treatise is intended to fill up that blank, if blank it may be called, in such a comprehensive work.

The number of shafts to be sunk must be regulated by the length of the Tunnel and the time allowed to the Contractor for its completion.

When mining work is well started it will be good progress if one "length" of complete Tunnel is mined and lined in every twenty "shifts," or in ten working days and nights, at every two "faces," or in each direction from a shaft; a "length" being, say, 5 yards long.

From each shaft a Tunnel is worked, that is to say mined and lined in each direction, except from those sunk at the two open ends (Nos. 1 and 5, Fig. 1), and in each direction there should be two working faces, one of them being due to working direct from the shaft, and the other by working back to the shaft from a "break up," which will be described presently.

Allowing that there are, at the utmost, six hundred working shifts per year, and that there is a full gang of miners at work for every two faces, thirty lengths would be mined and lined per annum in each direction from a shaft, fifteen of them being got in from "break up" face.

Thirty lengths, of 5 yards each, equals 150 lineal yards, as being the most to be expected to be completed for every two faces per annum.

Let us suppose, for example, that a Tunnel, 1 mile long, has to be completed in two years; how many shafts should be sunk on it to ensure such timely completion?

One shaft should be sunk at each end of the Tunnel, and the mining carried on from it in one direction only; in the other direction a heading may be driven, to serve for expediting the excavation of the cuttings leading up to the Tunnel, if they are heavy and long, as will be explained further on. Now it has been said that the possible work to be done in one direction from a shaft is 150 yards, and consequently in both directions 300 yards per annum, or

in one and a half years 225 and 450 yards respectively. From both the shafts at the open ends, 450 yards can be completed in a year and a half, leaving to be worked from intermediate shafts, 1210 yards. This length will require three such shafts, at the rate of 450 lineal yards each, and with this number there is a probability of the Tunnel being completed in the time specified; but as accidents and interruptions are not unlikely to occur, an extra shaft may be sunk, to ensure all being in time.

However, with five shafts, one and a half years will be needed for the mining and lining; sinking these shafts and driving the headings will take six months at least.

It is not advisable to commence a "break up" in the heading from a shaft until the headings are all through and the centre line accurately fixed in them, so that it will be seen that, with a Tunnel 1 mile long, with five shafts on it, two years is by no means too long a time for its completion, providing all goes well, and no serious interruption to work occurs.

In choosing the position of shafts, they should be as nearly equi-distant from each other as possible, and the lowest points on the surface should not be chosen in all cases for a site, for, although it would give a less depth to be sunk, all surface water and that pumped up the shaft, would naturally drain to and down it, and water is one of the greatest obstacles encountered in Tunnel works. Besides, the "bank," or top of a shaft, generally requires raising above the surface, in order to get tipping room for the spoil sent up from the workings.

A temporary working shaft should be 9 feet square clear of the timber, and sunk quite vertical.

The settings of timber should be at least good Memel, 10 inches by 10 inches, halved into one another at the angles, and plugged through the halving; the settings should be 4 feet apart between centres measuring vertically—the first one is placed at or about surface level—poling boards 1½ or 2 inches thick will not be too strong for the lining; if thicker boards than these are found to be necessary, short ends of planks will come in cheaply.

The first setting or frame having been let into the surface of the ground sufficiently to keep it steady, the poling boards are set up all round the outside of it, and the ground may then be excavated from the inside and from under the setting, the boards being hammered down, and following the excavation, temporary props being kept under the angles of the setting to prevent settling. When 4 feet has been so excavated another setting can be placed in position vertically under the first; take care that the lower ends of the poling boards are behind this second setting; the second setting being in place, good props must be placed from one setting to the other at the angles, and also some intermediate ones. Another set of poling boards may now be inserted behind this second setting and in front of the first set of boards already in position, and this second set are hammered down again, following the excavation, and so on.

If the ground all round and close to the shaft is level, then when two or three settings are in place in the shaft, the pit mouth should be raised some few feet by building up other settings of timber upon those already in place; this will give height for a tip for the excavation brought up the shaft.

A jack-roll may now be set up over the shaft or pit mouth, with two small skips or buckets attached on opposite sides of the winding barrel of the jack-roll, so that as one skip is ascending the shaft the empty one is descending to be filled. This method of raising the excavation and water from the shaft will serve very well for a depth of 10 or a dozen yards, but a winding engine or a horse-gin will be eventually required for raising and lowering the material of the Tunnel works; while the above described work is going on, arrangements must be made for erecting a head gearing over the pit mouth, and forming a gin ring with the excavation already coming or got out of the shaft.

When a pit is over 25 yards deep a horse-gin will be found too slow, and a winding engine will be required.

This engine should not be less than 14 h.p., of the ordinary

portable engine type, with its wheels taken off, and resting on a good solid bed. It should work by means of a good bolt on to a friction winding gear; this machine allows of the engine always working steadily one way, and does away with the dangerous stopping and reversing of the engine.

When a skip is required to descend the shaft, by means of a powerful screw the drum of the friction gear is thrown out of gear with the engine, and the skip descends by gravity; a powerful brake on the drum, worked by the foot, regulates the speed of the descent, and should be capable of instantly stopping it. A distinctive mark is often fastened to the steel wire rope to which the skip is attached, and this mark when seen by the breaksman passing over the pulley of the head-gear shows that the skip is at a certain distance from the bottom of the shaft; and another mark near the other end of the rope, which, when seen passing on to the winding drum, apprises the breaksman that the skip is near the top of the shaft, or bank, as it is termed; a bell in the engine-house should also be connected with the top and bottom of the shaft, which the skip in its ascent and descent rings when at a certain distance from the top or bottom. This bell, or hammer, is also made a means of communication between the bottom of the shaft and the engine.

When a skip is descending, the engine, although doing no work, should be kept quietly running, and when a full skip is attached and ready for lifting, the hanger-on at the pit bottom rings the bell, and the breaksman simply throws the drum into gear with the engine; this does away with all jerking.

Careful attention should be paid to the condition of the steel wire rope; it should be constantly examined, and to prevent wear and tear it should be painted now and then, as it is run slowly on or off the drum, with a coating composed of three parts Stockholm tar, one of pitch, one of tallow, and one of common soap, all boiled together and applied hot.

Over the pit mouth should be placed a bogie, or rolly, on four small iron wheels of about 12 or 15 inches diameter, and of a gauge

equal to the full width of the shaft, running on light rails laid far enough back into a sort of dock to allow of the rolly being pushed back quite clear of the pit mouth; on the rolly are laid light rails at 2 feet, or 2 feet 6 inches gauge, on which run little trollies. The full skip ascends clear of the pit, and is stopped; the rolly with the trolley on it is pushed over the mouth, and the skip gently let down on to the trolley and disconnected from the winding rope, and an empty skip attached for lowering; the rolly is then pushed back into the dock, having the full skip on it. To the end of the dock and at the level of the platform of the rolly converge lines of rails, on to one of which the trolley and skip are run away to the tip head.

A level bench mark having been carefully established near the shaft, the shaft is sunk to the proposed formation level of the Tunnel, which can be found by measuring down from the B.M. by means of rods which link together.

This process must be continued until the intended bottom of shaft is reached, and at the bottom and below formation a sumph must now be formed, in the same manner as for the shaft, to collect the water; three yards deep will be sufficient for a beginning, and until the probable amount of water likely to be met with can be ascertained; it can always be deepened if need be; over this sumph must be placed a strong and movable framework of timber, to form a cover, and able to withstand stones, etc., which may fall from the ascending skips.

CHAPTER III.

ON HEADINGS.

The shaft having been sunk, the next operation is that of driving the heading. A heading must be driven not only to afford communication all through the Tunnel and between the several working faces, but also to allow of the centre line of the Tunnel being accurately set out below ground.

Upon the question of the relative position of the heading a great diversity of opinion exists, as to whether it should be driven at about formation level, and be what is called a "bottom heading," or be driven with its top a certain distance higher than the extrados of the Tunnel arch, and be what is called a "top heading."

There are arguments in favour of both positions, and what the author now has to say upon the matter is not put forth with any idea of settling the question, but simply as the result of experience, and bearing in mind that a Tunnel in unsound ground is now being treated of. But it is a question worthy of much consideration, and the author having once helped to pay for the luxury of a top heading, and having found the cost far in excess of the benefit derived, he most strongly advises that all idea of a top heading in heavy ground be at once abandoned.

A Contractor is generally paid for driving one heading, and there is no doubt that a top heading must eventually be driven all through the Tunnel, not necessarily all at once, but certainly for each length as it is got out for lining, this top heading being needful for getting into position the crown bar, and it is argued that as

the driving of this heading for the bars is the most expensive operation of the mining, why not drive it right through the Tunnel at the outset, more especially as it will be paid for? It may be said that driving a continuous heading, whether "top" or "bottom," will cost about the same money, and it may be reasoned, if a Contractor must drive a top heading in any case, which undoubtedly he must, and that as he will be paid for a heading driven somewhere, why not drive it at the top?

This is about the only good argument in favour of driving a top instead of a bottom heading; but there are many against it.

Let us suppose that the thickness of lining is fixed at 2 feet 3 inches, or 6 half-brick courses, that the lengths proposed to be got out shall be 5 yards each, and that the bars necessary for supporting the ground while the length is being mined and lined shall be 1 foot 6 inches diameter at the butt or thick end, and that the superincumbent weight upon these bars will cause them to sag or settle down before the arch can be keyed, a depth of 12 inches: this is called the "drop;" and the bar must be kept up to that extent to allow for such sagging, in order that the brickwork may be got in of full thickness under the sagged bar.

Thus it will be seen that the top side, or "back" of the bar, must be 2 feet 6 inches higher than the extrados of the arch, and consequently the under side, or "belly" of the head tree of the top heading, must be kept sufficiently high up and above this to allow of the bar being placed under it.

Let a top heading be driven, and the first thing found to be inconvenient is, that on arriving at the two open ends of the Tunnel the passage through it is at a higher level than the formation of the cutting, and a consequent lift of some 15 feet for all material passing in or out of the Tunnel. Next you decide upon the position of the "break-up" between the shafts.

A "break-up" is formed by opening out and lining a length midway between two shafts, after the heading is driven between them; this creates at once two new working faces, and facilitates

the progress of the mining and lining, and allows of more hands being employed, and the work of finishing the Tunnel expedited.

One of these faces is worked backwards towards one shaft, and is manned by the same gang as works at this shaft, and the other face works in the opposite direction towards the other shaft, and belongs to the gang at that other shaft.

Now, as the break-up is being formed from a top heading, the bottom of which is about 15 feet above the formation level of the Tunnel, all excavation below the level of the bottom of the heading has to be raised into the heading, taken along it as far as the face working from the shaft, down that face to the shaft and up to the ground surface. Water has to be dealt with in the same way, and this process must continue until the faces worked from the shaft and break-up meet one another, and a very little of such work will make all hands sorry.

But these are not the worst or strongest arguments against a top heading.

Bearing in mind what has been said about the uncertainty of the weight to be supported and provided against, and having driven the top heading on the assumption that a certain thickness of lining, and certain bars with a certain drop will be sufficient, the first length is commenced, and before, perhaps, three of them are complete, the calculations are found valueless, and that a lining 3 feet thick, bars 2 feet diameter, with 18 inches drop, are absolutely required to withstand the weight. The top of the top heading has to be raised 18 inches or 2 feet all the way through the Tunnel, and that with an increase of weight on it, owing to the ground having been previously disturbed; this raising, in wet and heavy ground, is an exceedingly difficult operation, and will be found to cost quite 50 per cent. of the first cost of the heading.

It may be said, then, if this contingency is likely, why not drive the heading high enough out of harm's way to begin with? Do so; and if the first calculations as to thickness of lining, etc., are borne out, there will be so much more dry

packing to do between the brickwork and the roof of the mined ground.

Again, in driving a top heading, at the outset considerably stronger timber would have to be used, as some of it would have to remain under strain a long time, on an average for half the time during which the Tunnel is under construction, whereas the timber used for supporting a top heading driven for each length, as it is got out, would only remain under strain about ten days, and consequently need not be so strong. If "drawing bars" have to be employed (the nature of which will be explained), they will necessarily have to be placed under the head-trees of the top-heading, which head-trees form the top timber of the settings placed in the top heading to support the ground until the crown bar is in position and propped, and will remain in position until the brickwork of the length is keyed; the bars are then drawn, and serve again for the next length, but the head-trees cannot be got at, and have to remain in, and are lost; it is therefore a consideration that this timber should be no stronger than absolutely necessary.

In a light Tunnel no "drawing bars" are needed, all being what are called "taking-out bars," and when they are taken out these head-trees can be got out with them.

Again, there is always more or less face weight in a length, that is, a pressure tending to shove the face forward into the length, and often this causes a good deal of movement, and necessarily more near the top or roof of the length than near the bottom of it; this pressure dislocates the top heading timbers, and the settings will be found to be gradually leaning over towards the nearest working face, and to keep them up and the heading open, lining or intermediate settings will be needed, placed between those originally set, and also lacing boards spiked securely from head-tree to head-tree, and from side-tree to side-tree, to tie all together, and even with those precautions the author has seen utter collapse as a result of this face weight.

Lastly, a bottom heading has the advantage of becoming a drain for all water above it, and so keeps the work in the top dry.

The cases mentioned as likely to occur have all happened in the author's experience, and caused much loss of time and money, and as the use of experience is to avoid repetition of errors, he, for one, has made up his mind never again to drive a top heading through a Tunnel at the outset, unless previously assured that there will be but little weight, and that reasonable calculations as to lining, bars, etc., can be depended upon.

CHAPTER IV.

ON SETTING OUT LINES, DRIVING HEADINGS, AND FIXING POSITION OF WORKING FACES.

FROM the preceding Chapter it will be gathered that it is more desirable to drive a bottom heading. We will suppose that all the shafts are sunk to formation level, and that a good sumph has been formed under each, and that there is one shaft at either end of the Tunnel and three intermediate ones as nearly equi-distant from one another as practicable.

The centre line must be carefully and accurately set out on the surface over the Tunnel, and permanent points in it established, one on each side of each shaft, in the straight, if the line be straight, or in the tangent of the curve at the shaft, if the line be a curved one. These points should be well clear of all workings, so that they may not be disturbed.

Provide two copper wires sufficiently long to reach from top to bottom of either of the shafts; set up the theodolite over one of the points, and sight on to the other across the shaft; securely spike two pieces of board on some convenient part of the head-gearing, transversely to the line of the Tunnel, one on each side of the shaft, and as far apart as the width of the shaft will allow, so that the wires may hang from them freely; cut a notch in each board exactly in the centre line as fixed by the instrument, and let the wires be suspended in the notches with a heavy plumb-bob on

each (say 10lbs. weight, or heavier); these bobs should swing at the shaft bottom in a pail of muddy water, or oil, to keep them steady.

Care must be taken to see that the wires hang clear of all timber, etc., in the shaft.

The two wires are now in the exact centre line of the Tunnel, and their line can be transferred to some fixed point on either side of the shaft, by the eye, or by stretching a fine cord across them; this will be sufficiently near for driving 10 yards of heading on either side, but when this length is done more accurate lines will be required; the wires must be again swung and the theodolite taken down the shaft. Procure a lump of soft clay and stick it on the floor of the heading at a point about half-way between shaft and one face of heading, then with a plumb-bob attached to a fine line sight on to the line of the wires as near as possible with the eye, and make a mark in the clay where this bob drops; set the instrument over this mark, and sight on to the nearest of the two wires; by this time it will be found rather dark, and the cross hairs of the telescope undistinguishable; this must be provided against beforehand; any instrument-maker understands how to pierce one of the trunnions, and place in it a mirror and reflector; by holding a candle to the end of the trunnion and looking through the eye-piece the hairs will be distinctly and steadily visible.

To see the suspended wire, cause a man to hold a piece of white paper behind it, and behind the paper a lighted candle; the wire will then show plainly. Set the instrument on this wire and then have the wire gently moved to one side and the cross hairs should cut upon the other wire; if they do not do so, it is because the point in the clay is a little out. The instrument must be gently shifted until both wires coincide exactly with the cross hairs of the telescope.

A Transit Theodolite is indispensable for Tunnel work.

The centre line of the Tunnel is now on the instrument; procure two iron staples, and hammer one of them into the belly of

the head-tree of the heading, in the setting next but one or two to the face, and in this staple file a nick exactly in the centre line, and do the same at the other face of the heading on the other side of the shaft, without moving the position of the instrument.

By hanging plumb-lines in these nicks, the miners now have an accurate line, which will serve for another 20 yards or more each way.

Now, let me advise all young engineers to be very particular about giving these points in the centre line; let every point put in be exact, whether it is for permanent or temporary use. It will not do to be in a hurry and say, "Oh! that's near enough for what is wanted now." It never can be said when or how a point once put in may be used again; it is there and ought to be correct, and at some time in the dark the men mistake it for another, or the engineer forgets, perhaps, that he put it in only for a temporary purpose, and it gets worked off, and if only a little wrong it produces a great error sometimes before done with, and causes no end of trouble and rectification. There cannot be too many line points in a Tunnel, provided they are all correct; sometimes owing to pressure, slips, shots, etc., some may get moved; if, however, there are plenty of points, suspend lines to all and see how they look for line. Perhaps one or two will be found to be out with the others; if so, take the line of the majority and immediately obliterate the wrong ones. A great fuss is often made of the difficulty of placing working lines in a Tunnel; but it is very easy—only requiring a sound knowledge of the Theodolite and the properties of curved lines, plenty of patience, and a determination not to be beaten, and to have everything correct.

If the Tunnel is on the straight, and the heading fairly driven, it will be very easy to put in the working centre line for the mining, by dropping a single wire down each shaft, the wire being ranged in the true centre from above, then set the Theodolite at one shaft and sight on to the next forward, and reverse on to that backward; if the cross hairs do not cut on to both wires quite

correctly, halve the error at both shafts, and shift the instrument forward, and try the next shaft and so on, until you have all the five wires in a true line. Now carefully fix points in the heading, between the wires, at say every half chain, by driving a staple into the head-tree, and filing a nick in it.

These points thus established should be verified every now and then by going over the same process as described above. A Sunday is the best day for such verification, and indeed for putting all lines into a Tunnel; the men are not at work, and the workings are free from gunpowder smoke. Miners are an expensive class of men to keep idling about while lines are being placed, and the knowledge of this will often cause an engineer to over-hurry himself, and make errors, if he attempts the work on a week-day.

If, in checking lines, the points in the heading are found not to come in with the wires at the shafts, it does not follow that the points are wrong, for very often the mining works under cause the ground above to settle, shifting the points established near the shafts, and throwing the wires out.

If the Tunnel is on a curve, there is no difficulty about giving the lines, but there is more chance of error, as calculations of angles, etc., come into the process, and figures are apt to get wrong; twice two do not invariably make four when summing in a Tunnel.

The simplest way of giving lines on a curve is to drop one wire down the shaft exactly in the centre line, and then set the instrument in the line tangent to the curve at this wire, and let a second wire drop in this tangent line; then take the Theodolite down the shaft and produce this tangent line into the heading, placing points in it at every half chain; then calculate the off-sets from the tangent to the curve, and measure them off from each point, drive in staples and file nicks; and it is well also to make a neat plan of this proceeding, marking on it the tangent line, and points in it, and the off-sets to the curve at each, in plain figures, and give it to the foreman miner, who is, or should be, a very

intelligent fellow. A point may be lost or blown out by a shot, when the engineer is not at hand to help; the foreman will, if he understands the plan, be able to help himself.

Let not any engineer attempt to give curved lines on any rule of thumb principle, but always employ a Theodolite both above and below ground, as errors in the lines of a heading, although not serious, are a never-ending source of trouble, annoyance, and loss of time; besides which, if headings, driven from opposite faces, do not meet well, a jink is caused in the line of temporary metals, to be afterwards laid, and waggons will be continually getting off the road at this jink, and a full waggon off in a close heading is a serious business sometimes.

Of levels to be given in the heading, little need be said, as every engineer is conversant with the process. A B.M. having been established at the bottom of each shaft, by measuring down with rods, a brob should be driven into the timber at rail level, and painted some distinctive colour; and if the Tunnel is on a gradient, a board should be provided, about 15 feet long, with one edge quite straight, and the other cut to the inclination of the gradient; the foreman or ganger can then level from the B.M. and keep about right until sufficient heading is driven to allow of another B.M. being put in by the engineer.

The bottom of the heading should be kept about 1 foot above intended formation level; the size of the heading, clear of all timber, should be sufficient to allow of the free passage of a tip-waggon; because so soon as the headings are through, a line of temporary rails should be well and carefully laid through the entire length of the Tunnel, connected with the cuttings at either end, and with the outside works; this road will be found very convenient for bringing in heavy bars and long timbers, bricks and mortar, and for taking away the excavation from some of the faces.

A heading 7 feet 6 inches high, and 8 feet 6 inches wide at the underside of the head-tree, and between the side trees, will be sufficient.

While sinking the shafts, etc., a good supply of small larch timber should be provided for this, averaging from 6 to 10 inches diameter, and also plenty of poling boards, from 1 inch to 1½ inch thick, 6 inches to 9 inches wide, and about 4 feet long; and it may here be mentioned that if the ground is loose and shaky a great many such boards will be wanted, and the supply of them direct from a timber merchant is doubtful, and to be without them is every bit as bad as being without bricks and mortar; so to ensure a constant supply for a Tunnel 1 mile long, at least two circular saw benches should be set up and driven by the engines working the pits.

Scotch and spruce fir can generally be procured in the tree at from 8*d.* to 1*s.* 2*d.* per cube foot, depending, of course, upon the locality, and sawn on the spot, to any dimensions needed; a great many foot-blocks, cleats, and wedges, will be wanted, all of which can be cut out by these saws.

This sawing should not be done by piece-work; it causes much trouble in measuring the work done, and the miners will constantly come up the shaft and take down boards and wedges which have not been measured, and the sawyer's word must be taken as to quantity, as it is not possible for the timekeeper, or foreman, to be always about. By day-work, poling boards should be sawn for about 2*s.* 6*d.* to 3*s.* per 100 superficial feet, measuring one side of the board only. One cube foot of timber costs say 1*s.*, and will make 8 superficial feet of 1½ inch boards, and there will be at least 5 per cent. waste, so that poling boards will not cost less than 12*s.* per 100 superficial feet.

Larch timber, such as required for head and side trees, will cost 1*s.* 9*d.* to 2*s.* per cubic foot, and may be safely reckoned at 2*s.*, to include waste and tops.

The side trees when in position in the heading should have a sprag of 6 inches each, *i.e.*, should lean inwards to that extent at the top, so that if the distance between them at underside head tree is 8 feet 6 inches, at the bottom of the heading it should

be 9 feet 6 inches. Every side tree in a heavy Tunnel should be set upon a foot-block of hard wood, about 15 inches square, and 3 or 4 inches thick, and placed at about a level of 6 inches below proposed floor of heading; this is to give a wider bearing surface, and prevent the tree from sinking or cutting into the ground.

Sometimes, indeed very often, the floor of the heading will commence to rise, or spue up, owing to the pressure above, and if there are any signs of this, every other setting of side trees, and sometimes every setting, should be placed upon a good square timber or cill, running across the heading from one side to the other, below temporary rail level; the weight on the side trees keeps the ends of this timber down, and the weight of the road and passing waggons keeps the middle from rising.

Two side trees and one head tree, and when necessary a cill, form a "setting," and a setting should be placed at least every yard forward, the poling boards reaching from one head tree to the other, and overlapping 3 or 4 inches, and in soft ground these boards must be placed close together all round.

The cost of driving a heading of this size cannot be positively stated, as it varies directly with the nature of the ground; but in good sound shale, where water is not a serious obstacle, and weight moderate, the undermentioned figures may be a guide:

Let the head tree be 10 inches diameter, and side trees 8 inches diameter, and poled all round. Excavation per yard, forward = 10 feet 7 inches × 8 feet 6 inches, × 3 feet = 10 cubic yards.

This may be let piece-work for 30*s.* per yard, lineal, to include setting all timber, but not to include getting it down the shaft, nor pumping, nor horse at the gin, nor of foreman and time-keepers; these items will not cost less than another 10*s.* per lineal yard.

TIMBER.

		£	s.	d.
1 larch head tree 10 feet long × 10 inches diameter ...	= $5\frac{1}{2}$ cubic feet.			
2 larch side trees 8 feet long × 8 inches diameter ...	= $5\frac{1}{2}$,,			
Per yard lineal	11 cubic feet, at 2*s.*	1	2	0
2 hard wood footblocks, say		0	1	0
Poling boards $1\frac{1}{2}$ inches thick and 4 feet long 28 × 4 = 112 sup. feet, at 12*s.*		0	13	5

Add to this 5*s.* for use and sharpening of tools, and for spikes and brobs used, and the total per yard forward becomes £4 5*s.* 5*d.*, and to this again must be added 10 per cent. for contingencies and Contractor's profit, bringing the cost per yard forward of such a heading to, say £4 10*s.* And this price has been doubled in some Tunnels.

The poling boards will perhaps appear to be of an unnecessary thickness, but it must be remembered that some of them will have to remain in place until the Tunnel is nearly finished, and damp and rot very soon impair their strength.

A working gang, consisting of two miners and four labourers, will drive a yard forward per day easily at a face in good ground, and more sometimes, when no difficulty is experienced in getting the timber in.

From the shafts sunk at either end of the Tunnel it will be found advantageous to drive a heading back through the cuttings leading up to the Tunnel mouth, until it reaches the face at which the cutting excavators are working. (See Fig. 1.) Holes called "shoot holes" can then be driven upwards from the roof of the heading to the surface of the ground above; strong trap-doors are then fixed in the bottom of each hole at the level of the heading roof and opening downwards. Tip waggons can then be run under the holes, the doors opened, and the earth shovelled down from the top; when the waggon is full the trap-doors are closed, the navvies go on shovelling down, and the waggon is shoved forward and another brought up under the hole, and so on until the set is full. In good ground, indeed in almost any ground, two men at the hole will do as much as four filling in the ordinary way.

This method does not work so well in a wet, or rock cutting, as the water naturally all drains into the waggon, and by the time it has got to the tip-head its contents are all slurry, and rock falling down the holes breaks the doors and waggons.

The distance apart of these holes, measuring along the centre line, should be regulated by the depth of the cutting and by the slope at which the earth will stand, and should be such that a slope drawn from the centre of a hole in one direction in the vertical plane of the centre line should meet that drawn from the next hole in the other direction, at about the ground surface.

If the depth of cutting between any two proposed shoot-holes $= x$ and the slope at which the ground will stand is 1 to 1, the distance apart of the two holes $= 2x$. With five shafts there will be, if these cutting headings are proceeded with, two working faces at each, or ten faces in all, and if the work of heading driving is to be proceeded with rapidly, twenty gangs of men will be required, ten of them for the day and ten for the night shifts, so that if a gang consists of two miners and four labourers, forty miners and eighty labourers will be the strength; besides these, a boy between every two gangs, for fetching and carrying tools, etc.; a hanger-on at the bottom of each shaft, to attend to the skips, and ring the signal bell; and on the bank at least two banksmen, for landing and tipping the skips.

As the heading progresses, light iron rails, about 15 or 20lbs. per yard, are laid at a gauge of about 2 feet 6 inches, on which run little trollies, similar to those described as being required on the bank, and on these trollies are carried the skips; each skip contains about one-third of a cubic yard. As, however, it is intended to get tip waggons into the heading when it is driven through, and when communication is made with the outside works, it may perhaps be as well to at once lay the temporary waggon road, and on it place larger trollies, similar to those used by platelayers; these will carry three or four skips each journey; to draw these a pony will be

wanted, which can easily be let down the shaft and stabled in a recess made in the heading.

The shafts are 440 yards apart, giving 220 yards of heading to be driven from each face, which at one yard per shift for progress gives nearly four months as the time required to join all up. Of course, before this, the mining and lining can be commenced from the shafts, the Engineer having satisfied himself that the lines are correct; but it is really not wise to commence a break-up until the heading is through, at least between any two shafts; besides, a break-up is generally made mid-way between two shafts, and consequently at or about the point where the headings from the shafts meet.

The headings being all through, the Engineer must now give working centres again. He will have been able to judge pretty well how correct his first lines were, by the way in which the headings have met.

Let down one wire at each shaft, which wire must be carefully ranged into centre line from above, and begin with the Theodolite at one end of the Tunnel, working the centre line in from the cutting outside (we suppose the heading through that to be also complete), and run a trial line right through the Tunnel, leaving points as he proceeds, and checking on the wire at each shaft; this trial line requires going over two or three times generally, as it seldom comes in quite correct the first time, and having established this line correctly, go back and fill up with permanent points between those left on the trial line; take notes of the position of each of these points, so as to recognize them again and be able to swear to them. Mischievous persons, discharged men, etc., have been known to move these points for spite, or through ignorance.

Giving these lines in a Tunnel 1 mile long, will occupy two or three days, unless the first trial line was very lucky.

Level B.M.'s should also be established all along the heading, all at R.L., and plainly marked.

During the time occupied in driving these headings, a good

deal of water may have been tapped. This must be conducted to the sumphs under the shafts; and times are generally fixed for drawing it, as at breakfast time and dinner time, and at the change of shift, when there is always some time to spare before the oncoming shift gets to work, and is ready for sending full skips to the shaft; also generally the sumph is quite emptied on Sunday morning.

For drawing this water up the shaft, a large barrel is required, called a "landing barrel;" capacity 40 or 50 gallons, and this will serve all through the work, unless water comes in in very large quantities, in which case a steam pump will be found the best and cheapest means of getting rid of it.

The barrel mentioned must be very strong, and iron bound and hooped, one hoop being fixed just below the centre of gravity of the barrel when full, with two lugs or eyes in it opposite one another. To these lugs is attached a strong iron handle, passing from one eye, over the top of the barrel, to the other eye, and so attached that it can fall over to one side or other; to this handle is connected the winding rope, and on the top edge of the barrel are fixed two hinges, one leaf secured to the barrel and the other loose, and formed into two prongs, which prongs engage the handle when the barrel is being raised or lowered, and prevent it canting; on the full barrel arriving at bank, the men disengage the prongs by throwing the hinge back, and easily tip the barrel into the shoot provided for taking off the water; the barrel being swung below the centre of gravity, is tipped with ease without disconnecting it from the winding rope. Two thousand gallons per hour can be raised by this means at each pit.

While all this work has been in progress, the Contractors will have seen to the provision of a large supply of strong larch for bars, for supporting the mined length, also poling boards, and have been getting bricks on to the works, or more probably making them. An ordinary Tunnel for a double line, without an invert, and with walls and arch 2 feet 3 inches thick, and of the dimensions

shown on the figure, will contain 17¼ cubic yards of brickwork per yard forward. We may suppose each length turned to be 5 yards long, containing 86¼ cubic yards of brickwork. 350 bricks is not too many to reckon per cube yard; a length will, therefore, require the provision of 30,000 bricks; and as there are five shafts, in two of which one length each per ten days is to be turned (the work only progressing in one direction from them), and three shafts where two lengths each per ten days, one in each direction, are to be turned, there will have to be provided bricks sufficient for eight lengths in the course of each ten days, or 240,000, a quantity hardly obtainable in most localities: and even if they could be got, there would probably not be horses to lead them; for even supposing the locality to be surrounded with brick works, and the average lead to be 1 mile, a horse would make five journeys per day, and bring 300 bricks per journey, or 1500 per day; and as 24,000 are required, in order to keep up the supply, eighteen horses and carts would be required continually at work, to say nothing of all the other horses required for other work, so that to secure a constant and certain supply, the most, or at least half, of the bricks should if possible be made on the site of the work. Shale is capital brick material.

The section of the Tunnel and thickness of lining having been decided, for a double line 26 feet clear between the walls is necessary, but this width must be regulated by the projection of the carriage doors when open. The doors, when open wide, should clear the walls; and it must be remembered that when a Tunnel is on a curve, the cant or elevation of the outer rail throws the door further over; therefore keeping the same total width, the wall on the inside of the curve should be a few inches further from the centre line than that on the outside, that is to say, that the centre line is still the centre line between the rails, but is not that of the Tunnel; this little difference can easily be adjusted when the curve enters the straight again.

Centres or ribs for supporting the arch while being turned must be provided.

We have supposed five shafts, at three of which there will be two faces, one working each way, and at the other two shafts one face each, and between each two shafts a break-up is to be formed, which gives another two faces to each break-up, of which there will be four in this case, and consequently eight faces; so that we have eight faces due to the five shafts and eight to the breaks-up, or sixteen in all.

In a properly organised Tunnel, a length will be being mined in eight of these faces, and the bricklayers will be lining the eight others; but lucky the man who can keep things going in this style. Beer is the enemy that often defeats his best-considered plans.

Now, for supporting the arch of a 5 yard length, three ribs or centres, at least, are required, two of them called "intermediate," and the other "leading," and as the ribs should always be left standing in one length until the next at the same face is keyed, it follows that four intermediate and two leading ribs are required per face; $6 \times 16 = 96$ ribs in all, and these must be ready, and a few to spare for breakages, as the brickwork is commenced.

It will be seen from the drawing of the section of the Tunnel that the curve of the arch begins at about 6 feet above R.L., and this is the real springing of the arch; but to get the walls up to this height a scaffold will be needed, and when this scaffold is built it is as well to continue building the walls to a still higher level, and generally centres are set at about 9 feet above rails, and this point we will call "springing."

To build the ribs, lay down a good level platform, and on it with great accuracy describe the soffit line of the Tunnel to natural size, and mark the two springings and below this line another 2½ inches under it: this space is for lagging. As the Tunnel to be constructed is a heavy one, the ribs must be made of good seasoned ash or elm, and they should be built up of pieces called sweeps: each sweep being about 4 feet 6 inches long, by 15 inches deep, and 3 inches thick, for an intermediate rib three thicknesses of sweep, or 9 inches, will be best.

The sweeps all being sawn to the above dimensions, one edge of them must be neatly adzed to the exact shape of the soffit line (u. s. of laggings), always endeavouring to preserve the full depth of the sweep at the middle. Let us take the first layer and begin at the springing. Take a sweep and apply it to the soffit line on the platform at the springing, and mark this line, or curve, on the sweep, and adze off neatly; spike this sweep in place on the platform, its outer edge fitting the soffit, and then apply another sweep to the end of the one spiked down, mark and adze it to shape, and so on, until arriving at other springing. For the second layer proceed in the same way, only begin with half a sweep, and with the third layer begin with a whole sweep again; all will then break joint. To fasten all together, over every joint, whether inside or outside, visible or invisible, four iron plates 15 inches long, 2 inches wide, and ½ inch thick, must be placed, two on each side of the rib, opposite one another, and bolted completely through with four bolts to each plate, taking care that all the bolt heads are on the same side, and good screws and nuts are on the other; by keeping the heads all on the same side, the rib will be the more easily dragged about on the Tunnel scaffold, there being no bolt ends to catch in the timber, etc. A rib is sent into the Tunnel in halves, as being more easily handled, and is bolted together by the centre setters when ready for setting. A leading rib is constructed in the same manner precisely, but is composed of four thicknesses, or layers of sweeps, one of the two inside layers projecting 2½ inches above the others, or equal to the thickness of a lagging. This rib is set at the leading end of a length which is to be turned, the projecting rim exactly at the end of the brickwork to be built; this rib remains in place, and when the arch of the next length is ready for turning, the laggings find a bearing point on this rib on the other side of the rim, or projection; it also keeps the laggings from slipping, or being forced out of place. An intermediate rib will cost from £6 to £7, and a leading one from £9 to £10.

Among other necessaries for carrying on the brickwork are the side wall frames and distance rods. For the side frames take a sound board $1\frac{1}{2}$ inches thick, 12 inches wide, and 13 feet 6 inches long, plane it, and make one edge true and straight, and on the opposite edge mark up the distance from foundation of the wall to where the curve begins, and then lay down the curve of the wall to springing level, which we have stated is 9 feet above R.L.; shape the board to this curved line, and on one side of the board nail a piece of timber, projecting at R.L., which should be not less than 4 feet 6 inches above the foundation of the wall. Mark the courses of brickwork neatly by saw cuts all up the back, or curved edge of this frame; this will guide the bricklayers in keeping their courses level; also draw and scribe a plumb line on both sides of the frame, and cut a hole for a bob to swing in. Two of these frames will be required at each face, one for either wall.

The distance pieces are two rods, each exactly half the span of the Tunnel in length, with a cross head at one end of each. These should be of good seasoned timber, not liable to warp, and about $2\frac{1}{2}$ inches square.

Figs. No. 2, 3, and 4 show an elevation and sections of a rib.

CHAPTER V.

ON MINING AND TIMBERING.

EXCAVATING and building the brickwork of a Tunnel is done piece by piece, or in lengths, as they are termed; one length being mined and lined complete before any great amount of work is done in the next.

The length of a length must be determined by the probable weight which will require supporting on the bars before the brickwork can be commenced and brought up; also upon the size and quality of the timber procurable for bars. A length is seldom more than 6 yards long, generally 5 yards, and in a heavy Tunnel 4 yards, and this sometimes has to be reduced to 3 yards in length. Let us suppose that lengths of 5 yards each can be worked, and that the Tunnel is rather heavy, and that drawing bars are required. In a light Tunnel all bars carrying the roof can be taken out as the brickwork is built up to them, and are called "taking-out bars," that is to say, that the ground is excavated and mined as nearly as can be to the exact shape of the extrados of the brickwork, or lining, and therefore the back of the bars supporting the ground is just even with the back of the lining, excepting five or six of them at or about the crown of the arch, which are kept up a few inches to compensate for settlement and sag; the walls are built and the arch commenced, and when it comes up to the underside of the lowermost bar, it (the bar) is removed, and so on until all the bars are out and the arch keyed. It will be obvious that when the arch is complete all but about

4 feet (measuring transversely), the crown, or top bar, must be taken out, and that the ground and incomplete arch are thus left without any support but that of the centres, and that the pressure or weight must be very slight to allow of this; and that at the best of times it is a hazardous proceeding; but it saves the Contractor a good deal of expense, as will be gathered when the system of "drawing bars" is described.

When the ground is heavy, and pressure, or weight great, the arch and length cannot be left, as described above, without support, and the Contractor cannot afford to leave bars bricked in above the brickwork in every length, so what are called drawing bars are introduced: bars so placed that the arch can be keyed in under them, and that they then can be drawn out end-ways into the next length to be mined and used again.

The crown, or top bar, and two others on each side of it, making five in all, generally form a set of drawing bars. Those on each side the crown bar are called "third bars," because when they are in place there are three bars in; the next two are called fifth bars; next two seventh; and so on. The crown, third, and fifth bars, are usually all of the same size and strength, and for working in a 5 yard length must be 21 feet long at least, and in heavy ground should not be less than 16 inches diameter at the small end; they must be straight and free from knots or shakes, and should taper uniformly.

All the bars carrying the roof of the length are supported upon a top cill, which is placed at about 9 feet 6 inches from the underside of the crown bar, and stretches horizontally across the Tunnel at that level, and just at the leading end of the brickwork to be built. This top cill should not be less than 13 inches square and 27 feet long; of good memel or pitch-pine timber—(see Fig. No. 5). The roof bars are all propped off it, and it is again supported by props from another, or middle cill, which should be yet stronger and 33 feet long. Now this top cill cannot be got into place until the ground is mined or excavated down to its

position, and the ground cannot be mined without support from bars, and the bars in their turn must be supported temporarily until the top cill is in place, so that they must be long enough to allow of their being propped off firm ground ahead of the length under construction, ground which is not likely to be disturbed by the mining operations.

15 feet is the length of the "length"; 1 foot must be allowed on the bars for them to rest on the brickwork of the last arch turned, and 5 feet more is the least that should be allowed for the bar to project beyond the length, and be propped upon safe ground, making 21 feet as the length, of the roof bars. The best timber for bars is larch, and of the size mentioned will cost 2*s.* 6*d.* per cubic foot; so that a set of 5 drawing bars will cost £26. The bark should not be taken off; if removed the timber becomes slippery in damp places, and difficult for the miners to lift and handle.

To make a cill a whole baulk of the length required should be got, and then scarfed; this scarf should be 5 feet long, very neatly and carefully made; on the top and the bottom sides of the scarf a plate of iron is let in, 6 feet long, 4 inches wide, and 1¼ inch thick; and the two plates are bolted together through the cill, and enclosed by four iron glands; on the top side of the scarf is further placed a saddle of timber, the full width of the cill balk, 6 inches thick and 9 feet 6 inches long; the whole is then secured together by five more glands, made out of 2½ × ½ inch flat bar iron. The section of timber to be encircled or enclosed by these glands is, as has been said, 13 inches × 13 inches for the cill proper, and a saddle on it 13 × 6 inches, making 13 inches wide and 19 inches high. The gland is made in two parts, one part being formed into three sides, to take the bottom and the two sides of the cill and saddle; and on the ends of these two sides, which are made to project beyond the 19 inches required, are formed good screws with nuts. The fourth, or top side of the gland, is then made separately, and

long enough to afford of a hole being formed in both ends of it, to just pass over the screwed and projecting ends of the other piece; the first piece is then slipped over the cill from the underside; the second piece passed over the screwed ends, and the nuts then tightly screwed down, so that all is held firmly together, and makes the scarf perhaps the strongest part of the cill.

The reason for thus scarfing, is because an entire timber of the length required for a cill would be too long to be got into its place in the Tunnel, it being longer than the Tunnel is wide; it (the cill) is therefore sent into the length in halves, each half got separately into place, and then all bolted and screwed up by the miners. As a cill should serve, if no accident occurs, all through the work, it will have to be taken to pieces and put together again many times; therefore it is important that the screws and nuts of the glands be well made. A sketch of a cill is shown in Fig. No. 5. Having also got a good lot of strong, straight larch, from 8 inches to 12 inches diameter, and from 3 feet to 10 feet long, for props, all is ready to commence mining a length. We will suppose that the first side length, that is, the length next the shaft, is in and lined; getting this length in is very similar to what is going to be described, excepting that cills must be used at both ends of it, but if in sinking the shaft bad ground has been encountered, it will be safer to brick the crown and third bars in in the first side length, and not attempt to draw them, for fear of settlement deranging the shaft timber; the fifth bars in this case must be "taking out" bars. Let us suppose this has been done, and further, it may here be mentioned that the shaft length, or that directly under the shaft, is not to be got out and lined until the shaft is done with.

It has been decided to line the Tunnel with a thickness of 2 feet 3 inches of brickwork, and that the lengths to be got out one by one shall be 5 yards long, that to support this length five drawing bars shall be used, each 2 feet diameter at

the thick end, and that the drop to be allowed shall be 1 foot 6 inches, *i.e.*, the small end of the bar being borne upon the last toothing or end of the brick-work of the last length; the other end of the bar shall be set or placed at a higher level by 1 foot 6 inches, to allow for sagging and settlement and possible breakage; so that if the Tunnel from R.L., to soffit is 20 feet 3 inches, we have the back of the crown bar, at the leading end of the proposed length, as high up as 26 feet above R.L., and the belly or under side of the top heading head-tree must be still higher, to allow of this bar being got in under it.

The first side length is keyed, it has been understood, and as all the bars were taken out or bricked in, there are none to be drawn.

The first operation towards mining for the next, or second side length, as it is termed, is to drive a top-heading long enough to receive the crown bar which is to be placed in it; 21 or 22 feet will be enough,—high enough for a man to stand up in, and wide enough to take the thick end of the bar, say 3 feet in the clear under head-tree; the distance apart of the bars is generally about as much as from the elbow of a man's arm to the tips of the fingers, or say 1 foot 6 inches, so that to take 2 bars, 2 feet diameter at the thick end and 1 foot 6 inches apart, the heading must be 6 feet wide under the head-tree, and between side-trees; and sometimes in very heavy ground two crown bars are worked instead of one, as they together give a greater bearing for the head-tree and support it better when side bars are put in, and the side trees are taken out—with one crown bar, when the side trees of top heading are removed, the head-tree would only be supported in its middle, and great weight might snap it across; the heading must be supported by settings of head and side trees about 1 yard apart, and sufficiently strong to bear the weight for ten days or so, and the heading should be close poled all round.

The crown bar must be got up into this heading by the

help of a crab and tackle. Place a foot-block of hard wood, 3 inches thick, on the brick-work of the last toothing, and the small end of the bar upon the block, then rear the other end up until it is touching the head-tree of the heading, and temporarily prop it there; mind that the thick end of the bars are always leading, the thin end being on the toothing, otherwise it will not draw afterwards, besides there is more weight, or rather leverage from weight, at the leading end of the length being mined, than at the end supported by the last arch turned, and consequently more need of strength at that end.

As (see Fig. No. 7) the top cill will be placed at about 6 feet below the soffit of the arch, the ground at the far end of the top heading should be excavated down to a little below this level, right across the heading, by forming a sort of grave; in the bottom of this, good footblocks should be placed, on which will stand the long back props, supporting the bars until the top cill is in position; these back props should be 10 inches to 12 inches diameter, and up to 9 feet 9 inches long; the length of these, of course, varies as the position of the cill, the thickness of lining and drop, and also by the position the bars they support are in with regard to the curve of the arch soffit.

All props should be "collared," that is, on two opposite sides of their diameter at the top end, cut off about 1 inch, and run it out about 9 inches down the prop, and then hollow out the top of the prop to receive the round side of the bar, this gives a thorough bearing surface. and prevents the outsides of the prop from splitting, for when a split begins, there is no knowing what direction it may take, perhaps inwards, right into the heart of the wood.

The props should be set with a sprag; this term has been explained before, when driving the bottom heading was under notice, and in all cases it means that the prop is set out of the vertical line or with a batter, the top of it always being more in towards the length than the bottom.

The crown bar being in, and back propped, get in the third bars; these are placed in the same way exactly, allowing the same drop, but as they should follow the curve of the arch they are not quite so high above R.L. as the crown bar. The work of widening out for the third bars can be begun by removing the side-trees of the heading and the poling boards, and excavating from the sides. When the third bars are in, short timber stretchers should be put in between the bars at about every 5 feet, strutting one bar from the other, in order to distribute pressure, etc., and also that dog-headed spikes, or brobs, should be driven into the bar round the head of all props, four to a prop, to prevent them slipping or springing out of a position. When the excavation for the third bars is got out, poling boards must be placed, of course transversely to the length of the bar; the proper way of poling when the face of the excavation is straight is to insert the board above the last bar in, and hammer it down; but as the excavation here is curved, it is sufficient if the ground be scratched out from behind the bar on the underside, and the board hammered upwards, until held by the bar; the fifth, or last, of the set of drawing bars is now put into position, and they hold or secure the lower ends of the poling boards. These fifth bars must be back-propped similarly to the others.

For driving the top heading two miners and three labourers will be enough, and these men will get the crown and third bars into place with an occasional helping hand from the rest of the gang when getting the timber up into the heading. As space widens out, and the fifth bars are got in, another miner and two labourers can be sent to augment the strength in the length, and when the seventh bars are in there will be room for the whole gang. A gang generally consists of a ganger, whose wages should be 7s. to 7s. 6d. per shift, and he must work as a miner; three miners at 6s. 6d., and eight or nine labourers, whose wage varies from 4s. 6d. to 5s. 6d. per shift.

The fifth bars being in, and placed with 1 foot 6 inches drop

at their leading end, in placing the seventh bars this extra size of mined section due to this drop allowance must be begun to be worked out, and the bars below the fifth brought gradually nearer in to the line of the extrados of the brickwork, until at a few feet below the level of the top cill the line of the back of the brickwork is regained. The set of drawing bars occupy about 15 feet of the circumference of the mined section, and in a 5 yard length there are consequently 15 feet $\times$ 15 feet $\times$ 1 foot $=$ 225 cubic feet, or about $8\frac{1}{2}$ cubic yards excess of mining over and above the net section of the brickwork, owing to the allowance obliged to be made for drop, before this is worked out, and the net dimension of the bricked section regained; this excess is nearly trebled. If the Tunnel was light, and no drawing bars required, this excess would be saved. The seventh bars can be of smaller dimensions than the drawing bars, both as regards length and diameter, as they have not to remain under strain so long, nor have they so much weight to bear; they must, however, be longer than the actual length to be lined, as they will require back propping until the cill is in.

Let us now consider that the length is mined down to the level of the top-cill, and before any more excavation is proceeded with, the cill must be got in—the front or side of it facing the length must be a little more than 15 feet from the last toothing—(by "toothing" is always meant the end of the brickwork of the last length turned), and it extends horizontally across the length, and a couple of feet into the ground on each side behind the proposed brickwork; getting back these couple of feet is called driving the cill hole, and in hard or rocky ground is an expensive little piece of work, and dynamite will be found very effective in doing it. The cill is brought into the Tunnel in halves, with the saddle and glands loose, the ground or cill bed being levelled and the cill holes driven; place one half of the cill in its position, and level it all ways; slip on half of the glands with the screwed ends pointing upwards, and set up the remaining glands in about the position they should occupy on the other half cill, and drop this

half into place; see that the scarf fits closely and neatly; drive the glands into proper position with a hammer, and put on the saddle and iron-plates over the scarf, now place the gland plates over the screwed ends, and screw all up tight. If from wear and tear, or distortion, the glands do not all fit tightly, tighten up with wedges. Prop all the bars off this cill, taking care to collar the props and drive brobs in at both top and bottom, and tighten them all up as much as is possible by wedges under the props; the back props, which have up till now been supporting the bars, may be taken out.

Everything is now plain sailing, and arrangements should be made and ready for getting the excavation away quickly, as now begins the paying part of the work, if it pays at all, and if the stuff is to be shifted quickly and cheaply, now is the time.

Excavate down to the level of the top of the bottom heading, placing the bars further apart and poling not quite so closely; these bars may now be only a little longer than the length being mined, and average about 12 inches diameter; one end of them supported in the brickwork of the toothing, which can be cut out a little for their reception, and the other end supported by temporary raking props, at a point a little back in the length from the front of the cill.

At or about the level of the top of the bottom heading another cill is placed, the bottom of it being kept high enough to clear waggons, etc., passing through the heading from and to other faces; this cill is similar to the top one, but may with advantage be stronger, and is of necessity longer, because the Tunnel at this level is nearly full width; 26 feet and 4 feet 6 inches for thickness of lining of both walls, and say 1 foot 3 inches for cill hole on each side, makes 33 feet as the least length of this middle cill. Get this in in the same manner as the top one, and securely prop between the two cills, letting each middle cill prop be exactly under one of those above, supporting the bars from the top cill.

Two strong rakers must now be got in to support the top cill

from formation against face weight more particularly; they should be on very strong footblocks, and when in position, driven up tight with driving wedges, inserted between the end of the raker and the footblock; the top end of these rakers should be formed into a jaw, to take in the bottom face angle of the cill, and should be provided with a good iron gland, just below the jaw, to prevent splitting. These top cill rakers should be got in as soon as it is possible, even before the middle cill is in, or, in any case, temporary rakers should be used.

In getting out the remainder of the length, leave the sides in, and excavate the middle portion only, leaving side slopes like a cutting, and do not undermine the middle cill. On arriving at formation level, place two strong props on good footblocks, under the middle cill, on either side of the bottom heading, and place two rakers to this cill, similar to those for the top cill, only shorter.

The face weight is sometimes very heavy, tending to shove the cills into the length, especially when the Tunnel is inverted, and in that case, besides those rakers, cill stretchers will be wanted; stretching or strutting the cill ends from the last toothing, and if this is not effectual, rakers, called "Judkin Rakers," must be introduced; these are timbers abutting against one another at the centre of the cill face, and stretching or strutting it horizontally skew across the length to the toothing.

The excavation of the slopes left in may now be proceeded with, and all got out to formation level, quite across the Tunnel, beginning at the top of the slope, and putting in a light bar here and there, sufficiently near to one another for them to secure the ends of any poling boards that may be required to support the ground, these bars being supported by raking props at either end; should the ground be good, no bars will be required below the middle cill. Do not undermine or excavate under the middle cill, but leave a good footing of ground under it, until the rest of the length is out, then this ground must be taken out in bays, putting

a prop under the cill, from a footblock on formation, one by one, as the bays are got out.

Referring to Figures Nos. 6 and 7, the drawing bars are lettered (*a*), back props (*b*), top cill props (*c*), bricking in pieces (*d*), (to be described when the lining work is under notice), middle cill props (*e*), poling boards held in place by bricking-in pieces (*f*), top cill raker (*g*), cill stretcher (*h*), middle cill raker (*i*), top cill (*j*), middle cill (*k*), bottom cill, when inverted (*l*), middle cill props (*m*), head trees of top heading (*n*).

The foundations of the side walls may now be got out; these are usually carried to about 2 feet 6 inches below formation level, and should be got out as a trench, the net width of the lowest course of the brick footing (see Fig. 8); be sure that these foundations are level and solid; the water accumulating in them can be got out by hand pumping, or baled out by buckets.

We are supposing that each gang of miners has two faces to work at, and they should always have, for unless this is the case the whole gang will be idle while the bricklayers are in, lining. Let these two faces be A and B, and the work just described, as having been done in A face; while the mining of this length is going on, and before it is out, the bricklayers should have completed and keyed the arch of the length last got out in B face; immediately they have keyed, some of the miner's gang in A should be sent to drive the top heading for another length in B, and if all goes well, should be able to get the five bars drawn into that length before that in A is finished, there is then about room for the whole gang to get to work in this next length in B face, and not be idling about when they have finished in A. This desirable state of things does not always "come off," the bricklayer's gang may "get on the beer," as it is called, and neglecting their work, fail to get the arch in B keyed in time, so that you have the miner's gang with nothing to do, and on the principle of no work, no pay; if this state of things occur often, the miners will leave, and endeavour to find work where things are better regulated.

The regular Tunnel bricklayer, or "professional," is a thorn in the breast of the agent and foreman, but of him and his kind, more presently.

By the time a few lengths are out and lined at each shaft and break-up it is probable that a good deal of water has been tapped, and that the method of emptying the sumph by barrel is not sufficient. A steam pump is really the best and cheapest thing to erect. Messrs. Tangye, of Birmingham, make a suction and force pump, admirably suited to this purpose; one of them, capable of throwing 3000 gallons per hour, occupies no space, and can be fixed in a man-hole in the side wall of the Tunnel, near the bottom of the shaft, and locked up; the force pipe is conducted up the shaft, and the suction into the sumph, with a branch along the side wall to near the length being mined, and to this end can be screwed a flexible hose, with a good "snorer" on its end; a stop-cock should be fitted to each branch of the suction, so that communication can be cut off from either pipe. The steam for working the pump can be brought down the shaft, from the boiler of the winding engine, by means of a pipe, coated with some non-conducting composition, and this coating again enveloped in sacking to prevent its being knocked off. As the pump is locked up, no one but the regular driver or fitter can get at it, and if once set going, will not cease working till choked up with mud, and this mud can be cleaned out once a week. If the machine is not locked, the men will be curious to find out how it works, and so on, and soon put it out of gear.

CHAPTER VI.

ON LINING THE LENGTH.

The wall foundations being out, everything is ready for setting the side-wall frames. The engineer should carefully put a centre line point in the middle cill, from which point hang a plumb-bob; with one of the two distance-pieces, or rods before described, mark off the face of the walls by holding the rod cross-head at the bob-string, and by driving a spike into the timber, somewhere above R.L., where the other end of the rod comes; set up the frame with its back edge against this spike and plumb it by means of the bob in the frame, and the projecting piece of timber marking R.L. must be levelled to R.L. exactly; spike the frame securely in place, of course its place is at the leading end of the length, and close up to the cill; put the other frame up for the other wall in the same way.

When a first side length is being turned four of these frames will be wanted, one at each end of each wall. It is not unlikely that before getting to this stage of the work the drawing bars will be showing signs of giving way under the weight; if this be so, precaution must be taken to prevent them breaking, by working what is called a "horsehead" under them; suppose all the five drawing bars show weakness, but that the seventh bars are standing well. A "horsehead" is a timber with its ends resting on a bar on each side of the length, and stretching across it transversely, from which the weak bars can be propped; the horsehead should be placed under the points where the bars show

signs of giving. If the introduction of this horsehead throws too much strain on the seventh bars, or on those on which its ends rest, these bars must in their turn be propped from formation. Now the seventh bars are "taking out" bars, and the horsehead must come out with them; before taking it away, however, the weak bars must be re-propped off the centre ribs; in very bad cases the seventh bars will have to be bricked in, that is, left in position behind the brickwork of the arch, and not taken out, the horsehead also being left; when the arch is keyed and all secure the horsehead can be cut off level with the soffit line, and the ends left can be chiselled out and faced up with bricks, or the ends may be left without any danger to the work.

Bricks and mortar are now required in the length. It will doubtless be very inconvenient to send these materials in from the two open ends for all the faces, because of the number of these faces at work and the consequent incessant passage of waggons with excavation, etc. When eight or ten lengths have been turned at any face, a turn-out should be put in off the waggon road, that is, a siding where waggons can stand and allow others to pass them.

For a Tunnel of this length it will be well to have a mortar mill in each of the entrance cuttings, and also a stock of bricks, from which mortar, and, in like manner, bricks, can be sent in waggons to the faces at the shafts A B and D E, and the breaks-up working with them; but another mill should be placed on the Tunnel-top near shaft C, and also a stock of bricks got there, to supply the faces at that shaft, and also help those at B and D in the event of a break-down, or of the roads to and from the cuttings being too crowded at any time to allow of materials being sent from that direction. An ordinary tip-waggon with a dodger (*i.e.*, means to prevent its tipping), will make a good mortar waggon, the tail board being spiked up and raised, or made up to the full height of the sides; shifting boards must also be placed across the middle to divide it into

two compartments, and all made as nearly water-tight as possible. The bricks can be loaded into ordinary tip-waggons, and half a dozen sent into the Tunnel a few hours before the bricklayers are ready to start. A mortar spot must be provided, that is, a place wherein the mortar can be unloaded; this spot can be made out off an old tip-waggon body, placed in the last length turned, nearest to that under construction. A supply of saw-dust is necessary. It is the bricklayer's labourers' duty to unload all these materials, and to handle them generally after they are delivered in the length. A labourer in a Tunnel will not use a hod: they say it hurts their shoulder, and that the tail, or handle, is always in the way; and these men's likes and dislikes have to be attended to somewhat. So head-boards are generally provided, or boxes, in which they carry the mortar on to the scaffold and shoot it off their heads out of the board or box, without the man having to go up on to the scaffold at all. To make the mortar leave the board easily and cleanly, it should be well littered with saw-dust. Mortar should not be stiff nor yet too sloppy; made to leave the trowel cleanly, and be free from lumps either of lime or ash. All bricks, if newly made, or which may have been exposed to heat or dry weather, should be thoroughly saturated with water before use.

A gang for lining a length consists of four bricklayers and six labourers, and these are divided into two sides, and each side usually works on the same side of all the lengths, so that the work on that side of the Tunnel may be similar; no two bricklayers ever work quite the samo until they have been to-together some little time. The best and neatest of the bricklayers usually take the leading or toothing end of the length on his side.

The leading end of a length is called the "toothing," because it has been, and still is in some Tunnels the practice to leave the bricks at this end projecting every alternate course, as the bond causes them to be laid, and they then form a bond

for the next length to be joined to it, and by this means it is vainly hoped that the junctions of the different lengths will not be noticeable, and that the work is stronger.

The author's opinion is against this practice of leaving a toothing, and he prefers every length to be finished up fair and square, or to be what is called "blocked;" it has in the end a much neater appearance, and is quite as strong as continuing the bond from one length to another by toothing the bricks.

A length should be, and is, complete in itself, and requires no help from the next; and as one length is lined several days before the next is commenced, there is time for some settlement of the work to take place; the consequence being that if the bricks have been toothed in this first length, the next when built to it settles in like manner, and the bricks tear out of the toothing, and in doing so many become broken, and this damage has to be patched up, and always looks weak, even if it is not so. Again, the courses of the length under construction may not be started at exactly the same level as the last, and to get the bricks into the last toothing a little squeezing, or forcing of the courses has to be resorted to, the result being that when the length is complete, and the scaffold, timber, etc., removed, the first three or four bricks in every course of the new length at its junction with the last, are found to be running up or down out of the general level of the course: a very unsightly piece of work.

The author therefore recommends a "block" toothing in all cases where bricks are used for lining; stone side walls are another matter. English bond is the best for the side walls, but of the bond for the arch a word or two may be necessary presently. The first course of the wall footings may be laid dry, *i.e.*, without mortar, and the footings should have a half-brick projection every two courses in height—see Fig. No. 8—but in heavy ground, portions of these footings are carried up plumb to formation level, *i.e.*, of the full width of the bottom course—this is shown also on

Fig. No. 8. On these solid "stick-ups," as they are called, are afterwards set the cills and props for supporting the centre ribs. Before the brickwork of the wall arrives at R.L. care should be taken to level the courses, so that they be not tending up or down (excepting in the case of a gradient), and at R.L., as shown by the piece of timber on the wall frame, leave a projecting brick at or near the leading end, as a guide for the next length, and for reference in setting the centres of this length. A line should now be stretched from the saw cut in the wall frame marking the courses to the corresponding course of the last length, and so on, following the courses marked on the frame until springing level, the top of the frame, is attained; a temporary scaffold will be required to attain this height; the bricklayer's gang make this, and carry the bricks and mortar up on to it. It is not necessary to set every brick separately in a bed of mortar, excepting those on the face; one course of the whole thickness of the wall being laid, it must be well grouted with mortar, and a good layer spread over the top of it; the bricklayer, in laying the next course, places the brick on this layer of mortar, a little ahead of its proper position, and sweeps it back to its place, thereby carrying sufficient mortar along with it to fill the joint. Every course should be grouted and every joint flushed up.

As the brickwork comes up, all or any cavities between the back of work and the mined ground must be carefully packed solid with hard material, such as pieces of rock, brick-bats, etc.; a miner's labourer or two are generally deputed to do this work, and to help the bricklayer's gang in taking out the bars, as the work comes up to them.

Should the mined ground in any case be found to have been got out too small, it must be poled back, that is, the ground must be very carefully removed from behind the poling boards, until sufficient room is got for the brickwork; a miner should be put to do this, because sometimes in heavy or loose

ground, this operation causes the ground from behind the boards and bars above to "run," and a run is a very dangerous thing, as it is sometimes difficult to stop, and lets the timber above give; an experienced miner will, as he works, suspect and provide for such a mishap.

The bricklayers once having begun, should not leave their work until the walls are complete up to springing level, and this being done, a gang comes in to set the centres or ribs. The ribs required for a 5 yard length are, as has been said, three in number, viz., two intermediate and one leading. We have supposed the first side length turned, and that we are now describing the second side length, and that the ground is so heavy that it is impolitic to remove or strike the centres under the first length until the next is turned, so that another set of ribs must be got into the Tunnel.

To set the ribs. On the "stick-ups," described as being carried up with the footings, place a half timber, 12 inches × 6 inches, and running the whole length of the side wall, and on it set up the props which are to carry the ribs (see Fig. No. 8)—the two intermediate ribs should be placed about 5 feet apart, one on each side the transverse centre line of the length; on the props, place another half timber, and dog it securely to the props—on this timber rest the slack-blocks and also the scaffold byats, stretching across the length from one side to the other, and say four in number; on these are placed the scaffold planks. It will be better to prop these byats off formation at two points in their length, one on each side of the waggon road, as, besides the workmen, there will be on this scaffold, bricks, mortar, laggings, bars, and ribs. Some of the miner's gang generally set up the centres, etc., but it is the duty of the bricklayer's gang to make the scaffold. This scaffold being made, the ribs are got upon it out of the waggons, each rib being in halves, and they are now bolted together on it, and roared into place by the help of a tackle, swinging from

a bar above; under the heels of each rib set a pair of slack-blocks, made of hard wood, each block being about 15 inches long, and 6 inches thick at one end and 3 at the other. In setting the ribs, care should be taken as to which way they will be afterwards lowered on to the scaffold, to go forward for another length; they should be set so as to descend with the bolt ends and nuts uppermost. The leading rib, now being set, should be so placed that the laggings provided (which should be 15 feet long by 7½ inches by 2½ inches) will reach and fit nicely between the groove or projecting sweep in the rib under the last toothing and that on the one now being put up. Lace all the ribs together by spiking pieces of plank or boards upon their undersides, here and there, and drive up the slack-blocks, until the crowns of the ribs are all nicely level, and about 1 inch high, to allow for after-settlement in the work. Weak or sprung bars can now be propped off the ribs. All the laggings required to cover the ribs must be in readiness on the back scaffold, or the scaffold still standing under the last length.

A shift's wages are usually allowed to one miner and four labourers for setting centres of a length, and this is considered a picking for them, as the work can be done in less time, easily.

The bricks, in waggons, must now be got up under the scaffold, and the bricklayer's labourers come in and throw them upon the scaffold, a few planks being left out of the middle of it, for this purpose; the mortar is placed in the mortar spot before-mentioned.

One lagging on each side, at the arch-springing, is now put in place, and the bricklayers begin their work, standing on the scaffold between, or in the bays of the ribs, and go on putting on lagging by lagging as they require them, and as the work comes up.

When ribs have been used several times under great weight, they become distorted, and the laggings will not bear on them

in places, so that wedges must be used under the laggings, to keep them up to proper line, and to allow of no sagging or springing in them.

Work goes on until the under side of the lowermost bar is reached, a couple of miner's labourers being told off to do the packing and help at getting these bars out, and this is done by the help of a tackle, swung from one of the drawing bars; the bar to be taken out is gradually and carefully raised a little, so that another course of brickwork can be got in to secure and hold fast the ends of the poling boards now being released by the bar; in heavy ground, most, if not all, of the boards round the arch will have to be left in behind the brickwork, to secure the ground against running. When the ends of the boards are secured, the bar can be lifted out of its place and turned about until it can be got through a bay of the ribs and back upon the scaffold, under the last length; this taking out of bars is often very troublesome work, especially where many ribs are needed, and the nearer the crown the worse it gets, as things are more crowded.

A word or two will not be out of place here, as to the bond of the brickwork for the arch. Some engineers insist upon English bond throughout, others prefer "single ring work," all bricks being laid as stretchers, with bonders of headers, where possible; the author prefers this latter method, as it secures good work, more bricks and less mortar being used, and he believes it to be an acknowledged fact, that the more bricks and the less mortar there are in a piece of work, the better is that work, always providing that there is a sufficiency of mortar in any case to properly bed the bricks.

A joint of $\frac{1}{4}$ inch in thickness on the soffit, if properly radiated from the centre, will be much thicker at the back or extrados of the brick, and will have to be so made, if the courses are to radiate. Suppose a course of stretchers to have been laid, of the whole thickness of the arch, on this will be superposed a

course of headers, if English bond is employed, the mortar joints at the inside ends of these headers will be much thicker than at the outside ends, if the bricks are well "summered," and the back brick of all will require a very thick bed to keep it up to the radiating line of the face brick, and as so much mortar has to be used, so much the more will the after-settlement be, and in a wet Tunnel the mortar gets washed out of the joints, and the more there is to be washed out, the worse for the safety of the arch.

In the case of single ring work, as the length round the arch on the soffit is shorter than that round the extrados, and having the same number of courses laid in each ring up the lagging, and the mortar joints all of the same thickness, the courses more remote from the soffit will be found to be gradually getting left behind; this goes on until the soffit ring has gained a whole course on the one behind it; the two rings can then be made level, and a header laid over them, and the same with the third and fourth and the fifth and sixth rings, and at intervals all the six rings can be brought up to the summering or radiating line together, and then a heading course laid through the whole thickness of the arch. Some engineers contend that in a single ring work there are so many distinct arches, each only half a brick thick; but this is hardly a sound argument against the system, because the line of pressure transmitted through an arch seldom, if ever, takes the form of the arch (and certainly not in a Tunnel where pressure is very unequal, being either all crown or all side weight), but follows a line of its own, tending sometimes out of the arch at the extrados of the haunches, and below it at the crown, and *vice versâ*. Many works written on equilibrium clearly demonstrate this line of unequal pressure; but to show how this question of bond is treated, it may be mentioned that of two great Railway Companies running out of London, one insists upon English bond and the other upon single ring for their Tunnel work.

To return to the business of lining the length, the arch may be built up to the level of the top cill, when what is called a bricking-in piece must be introduced; when the mining of the length was being described it was shown that before the top cill could be got in, the bars above it had to be back propped ahead of this cill, and as the brickwork of the length cannot be built further forward than the cill, and as all bars must sooner or later be taken out or drawn, it follows that there will be a few feet of mined ground ahead of the toothing now being formed, already mined and poled with boards, but without any support whatever, when the bars are out or drawn, and it would not be safe to so leave it; bricking-in pieces are therefore put in, they are of timber, about 8 feet long and 6 inches × 6 inches or so, and are placed behind the brickwork between each two bars, three feet or so of their length resting on the brickwork, and the remaining 5 feet projecting along the roof of the mined ground ahead of the toothing; these pieces must be securely packed from the brickwork before the bar is taken out, and they will then hold up the poling boards and ground spoken of. These are marked (*d*), Fig. No. 7. The seventh bars are the last taking out bars, and before getting up to this height the bricklayers will have had to make a temporary scaffold on the main one; this can be done with tressles and planks, or better still by hanging irons attached to the ribs. On the lower side of the fifth bars, and between each two drawing bars, must be built a dry brick packing 9 inches wide, and extending from the extrados to the poling boards above the bars, and must extend throughout, and in direction of the length; these packings serve to support the ground, and prevent it settling down and pinning in the bars as they are being drawn into the next length. They are marked (*o*), Fig. 6. The taking out bars being all out (for their assistance at this work the bricklayer's gang receive five shillings worth of beer per length, which should be allowed to be drunk on the scaffold), bricking the arch continues uninter-

ruptedly under the drawing bars, except building the dry packings; but as the men building the two sides are getting at rather close quarters, one side stands off until the other side has completed up to key, or within 1 foot 3 inches, or 1 foot 6 inches of the crown; when that is done the other side again comes to work and finishes their side up to the same relative point. The last lagging that has been put on on each side must be grooved on its top edge, that is, must have a groove or rabbit cut in it about 1 inch deep, running the length of the lagging, on which the "block" laggings rest—these are pieces of board 1 inch thick at either end, and bellying to 2 inches thick in the middle, and are about 2 feet 6 inches or 3 feet long, and are used for building the key, and are laid transversely to the other laggings. One side only, or half the gang, builds the key, and they take it by turns, one half gang doing this key and the other half gang the key of the next length.

Building the key commences at the toothing of the last length, and is worked forward; the bricklayer stands facing the toothing, and places a block lagging on, and lays the bricks towards him, building up the whole thickness of the arch as he comes, and also the dry packing over it (if two crown bars have been employed); having got one lagging filled he places another, and so on until all is complete. Care must be taken that the key is quite tight.

An inspector should be continually about, watching that no dry or slovenly work is put in, particularly should he be there while the arch is being keyed; this work at the key is cramped and arduous, and the best of men will sometimes be tempted to scamp it a little, especially as by this time they are nearly tired out. The first day on the arch a full gang should get on twelve or fifteen laggings on each side, they should then leave it and come again next morning and stay 'till the work is complete and keyed, as leaving it when nearly up to key is attended with risk, everything then being under great strain, all the weight being on

it that is likely to come. A full gang working steadily will line a 5 yard length in forty-two hours if they so choose, but fifty-five may be set down as a fair average time. The Tunnel bricklayer as a rule works by piece-work, or properly speaking by the shift. For a 5 yard length, with lining 2 feet 3 inches thick, and section as per drawing without invert, containing 86½ cubic yards of brickwork, twenty-seven shifts to the bricklayers are allowed, thus —2½ shifts for the walls, 3¾ for the arch up to key, and ½ shift for the key per man of the bricklayers, and as there are four in each full gang, it equals twenty-seven shifts in all, say at 6*s.* per shift = £8 2*s.* The labourers are six in number, and are paid the same shifts at 4*s.* each, and as there are one-third more labourers than bricklayers, at one-third less money per shift, they receive another £8 2*s.* among them.

As already said, one side takes the key by turns, the side building it receiving from the other the half shift allowed, so one side receives 7¼ shifts and the other 6¼ shifts per man, which is doubtless very good pay for working hard. 86½ cubic yards cost £16 4*s.* for the labour, or 3*s.* 10*d.* per cubic yard; to this must be added, however, the wages of the miners attending on them, the cost of setting centres, bar beer, loading bricks and mortar, and grinding mortar, and getting them into the Tunnel; all this will cost at least another shilling, and bring the cost per cubic yard to, say 5*s.* Tunnel bricklayers are among the men who work the hardest and for the longest consecutive periods of any that enter a Tunnel, and they also can and do drink more beer than any, and this causes them to be very uncertain in their attendance to work, and consequently a source of great annoyance to the manager; the men here referred to are the regular, or as they may be termed, the professional bricklayers and labourers; they will work, as has been said, for long shifts, and then go out and get so fearfully intoxicated that they cannot be got to work again perhaps for a week or more; and again, if the gang is not all on the spot, one bricklayer, or sometimes even only one labourer

being absent, the rest will not go into the length to work, but make it an excuse to go off and find the missing ones and get back to the beer. They have a Union among themselves, and if one is discharged he is simply kept by the others until he finds work elsewhere; he visits his friends at all other Tunnel works, and from each bricklayer at work he receives 2*s.*, and from each labourer 1*s.* 3*d.* per week, so that with a fair amount of work going on a man sometimes makes more by his "regulars" than he can do by working.

To have a length out and standing on the timber for days, waiting until the bricklayer's gang are sober enough or willing to go to work, is a very serious thing, and often places the safety of the Tunnel in jeopardy; besides which it throws the whole workings out of gear. The best remedy for such a contingency is not to employ such men, but to form a gang of your own men whom you know and can trust to work steadily if well paid for it; a little practice soon makes them as good and as quick as their professional brethren.

In lining a Tunnel one mile long every professional bricklayer in England will probably lay a few bricks in it. The surest remedy is to sublet the work to a really good man, and give him also several bridges, and say a viaduct as well; when the Tunnel is short of men he can then go and get recruits from this other work, and so keep the Tunnel going.

CHAPTER VII.

DRAWING THE BARS, ETC.

THE process of mining and lining a length of Tunnel having now been described, it yet remains to state how the drawing bars are drawn for the next length. Strike or remove the props which support the bars from the top cill, commencing, of course, with the crown bar. If the weight has not been very severe, and the allowance made for "drop" has been ample, the bar will have a little play and fall, or drop upon the brickwork of the arch, and be loose; if so, it can be drawn with a "devil," a stout iron bar, about 6 feet long, and having a slightly hooked claw at one end, this end should be formed of square bar iron; the claw end is inserted under the bar, and using the brick toothing as a fulcrum, lever the bar forward until it is quite loose and comes easily, it may then be drawn out by means of a small crab. But, if the weight has been great, and the bar has come down or settled a good deal, so much so that the full thickness of the arch has with difficulty been got in under it, a "Joe Smith" must be employed; the parts of this instrument are a strong male screw, about 4 feet long and 2½ or 3 inches diameter, with a very slow pitch, at one end of which is a strong loop or eye, a strong timber (*b*), either oak or elm, about 5 feet long × 9 inches × 6 inches thick, in the middle of which is inserted a female screw, through which the male screw works; a strong hexagonal nut must also be provided, working also on the screw, and a spanner, with a handle 4 or 5 feet long, fitting the nut. To draw the

bar, put a strong chain on the bar-end and fasten it to the eye on the long screw, pass the screw through the female screw in the timber (*b*), and put the nut on the screw on that side of the timber (*b*) remote from the bar. Now horizontally strut the two ends of the timber (*b*) from the brick toothing, by struts sufficiently long to stretch the chain tight, and then with the spanner work the nut—this draws the long screw through the female, and with it the bar; the bar must come or something must give way. If great power is needed to start the bar, a set of blocks and tackle can be applied to the spanner. In some cases of great weight on any particular length, it is good policy for the engineer to order the bars to be left in, to keep all secure; of course, in that case, the contractor is paid for the timber so left. In a junction length, that is, a length joining the two faces working from opposite sides, the bars must be left in of necessity, there being no room for them to be got out.

When the bars are drawn, the bar-holes or cavities between the dry brick packings, previously occupied by the bars, must be securely and tightly packed with hard material; there is room in the bar-hole for a boy to creep in and have this material handed to him, and for him to build it in place.

If the side weight should be severe, and the walls when built show any signs of bulging, or if the foundations of the walls are in weak ground, an invert should be introduced; this is a very simple operation, the chief difficulty being the water which naturally collects in the excavation for it. When an invert is necessary, a third or bottom cill will be wanted, at about formation level, and the middle cill must be propped from it; also most of the timber previously used for supporting the ground, will have to be strengthened or the lengths got out shortened, as the excavation for an invert causes a great increase of weight to be thrown on the length. This excavation is got out and kept to form by means of a frame made to the shape of the back of the brickwork, and spiked to the bottom cill. In building, the brickwork should be commenced in

the centre, and worked up towards the side walls, and great care must be taken to have the skew-back or junction between the invert and side walls well formed. Where 2 feet 3 inches thickness of walls and arch is sufficient, 18 inches will generally be enough for the thickness of the invert.

At every half chain, alternately on each side of the Tunnel, a man-hole or recess should be constructed, about 6 feet in height, and 1 foot 6 inches deep, and 3 feet 6 inches wide, arched over the top; the same thickness of work as in the walls should be retained behind the recess, but the work at the angles it makes at the back of the wall should be strengthened. These recesses are built as the walls are got up, and the bricklayers are paid about 10*s.* extra per man-hole, for the extra labour of forming them. When, however, one of them happens to come very near the leading end of a length, it is better to leave it out until the wall is quite settled, and some lengths lined in advance of it, and then let it be cut out afterwards; the reason for thus omitting to build it at the time the walls were being got up is, that being so near the end, it would weaken the toothing and wall to such an extent as perhaps to cause the arch to give way.

When 100 yards or more of a Tunnel is lined and complete at any face, the temporary road can be slewed to one side, and the centre drain put in. This drain may be 12 inches wide, and 18 inches high in the clear, and this size will be ample for most cases. A good flag, 4 inches thick, extending under the sides of the drain, should be laid in the bottom, the sides built of good bricks or flat bedded stone, laid dry, and about 14 inches thick, and over all, another good flag, 6 inches thick, bedded in mortar, but with the joints open; the top of this flag should be at formation level, and the formation should rise from this flag towards the Tunnel side walls each way, to give a fall for all water; this fall may be 6 inches. If the foundations of the side walls of the Tunnel are at all weak, let not the bottom of this drain be less than 1 foot above the level of such foundation, or the excavation for the drain will disturb the stability of the walls.

While the work is proceeding, the engineer will do well to put level B.M.'s on the side walls, opposite one another, and paint them plainly, then stretch a line across the Tunnel between these B.M.'s, and with a rod take the height of the soffit at intervals, soon after the arch is turned; by renewing his measurements now and then, he will be able to see if the brickwork is sinking or settling to any serious extent, and judge as to whether the strength of the arch is sufficient.

Also the engineer should, now and again, examine the side wall frames, and see that they are of correct dimensions, with no thumb screws or other appliances about them, and that they are made all in one piece; dishonest sub-contractors and workmen are still to be found, and by taking the aforesaid soffit measurements, and by examining the frames, he will satisfy himself that no "hanky-panky" work is being done or attempted, and if there is, be able to detect it before it becomes a serious matter. And, as before mentioned, in all these operations good or strict and steady supervision is necessary, both on the part of the agent, and also by the foreman miner; the author has constructed some Tunnels through very bad ground, and has been fortunate in never having had a serious mishap, and this freedom from accident he has much pleasure in here stating was in a great measure due to the untiring energy and practical skill of his foreman miner, Mr. William Jenkinson.

CHAPTER VIII.

ON COST.

A WORD or two about cost may be useful, although it must be remembered that the ground through which a tunnel is driven varies so much, that it is impossible to give any figures which can be taken as a rule. The undermentioned computation is for heavy ground, and is founded upon actual work done.

An average for the mining, or excavating labour of a 5 yard length is 169 shifts of one man, and the average wages per man is about *5s. 6d.* per shift; this includes ganger and lights. The time taken to excavate such a length ready for lining may be set down at six days and seven nights.

For a 5 yard length :—		£	s.	d.
Driving the bottom heading ...	£4 10*s*. × 5 =	22	10	0
Labour of excavating, getting in timber, and timbering	169 shifts at 5*s*. 6*d*.	46	9	6
Hanger on	13 ,, 4*s*. 3*d*.	2	15	3
Banksmen	26 ,, 4*s*. 3*d*.	5	10	6
Engine driver	13 ,, 6*s*. 0*d*.	3	18	0
Coals, etc., for engine ...	13 ,, 7*s*. 6*d*.	4	17	6
Candles and lights, say	75lbs. at 6*d*.	1	17	6
Pumping, including fitter, coal and stores	13 shifts at 9*s*. 3*d*.	6	0	3
Carried to Summary		£93	18	6

	£	s.	d.
Timber required per face:—			
NOTE.—This estimate may without exaggeration be at least trebled for breakages, loss, etc., and in a Tunnel one mile long, and with five shafts and four breaks-up; the quantity may possibly serve for 110 lineal yards.			
Set of drawing bars, each 21 feet long × 20 inches average diameter = 226 cubic feet, at 2*s.* 6*d.*	28	5	0
6 bars, viz., the 7th, 9th, and 11th, each 18 feet 6 inches long × 15 inches diameter = 135½ cubic feet, at 2*s.* 3*d.*	15	5	0
Say 8 bars below the top cill, 4 on each side, 16 feet long × 12 inches diameter = 94 cubic feet, at 2*s.* 3*d.*	10	11	6
Stretchers between bars down to top cill, say 4 per bar, each 1 foot 6 inches × 4 inches diameter = 40 feet × 1 foot 6 inches × 4^2 inches × ·78 = 47 cubic feet at 2*s.*	4	14	0
Top cill props—64 lineal feet × 9 inches diameter = 28 cubic feet at 2*s.*	2	16	0
Middle cill props—71½ lineal feet × 7 inches diameter = 18¼ cubic feet at 2*s.*	1	17	0
Top cill—31½ feet long × 15 inches × 15 inches = 49 cubic feet, at 3*s.*	7	7	0
Iron work for scarf, 224lbs., at 4*d.*	3	14	8
Middle cill—35 feet long × 15 inches × 15 inches = 54½ cubic feet, at 3*s.*	8	3	6
Iron work for scarf of do., 240lbs., at 4*d.*	4	0	0
Poling boards; those below the top cill may be got out and used again, but those above in heavy ground will be built in—			
Below the cill—5 boards per side, each 4 feet long = 20 × 15 × 2 = 600 square feet, at 12*s.*	3	12	0
Long back props—92 lineal feet × 12 inches diameter = 72 cubic feet, at 2*s.*	7	4	0
2 top cill rakers—22 feet long × 15 inches × 15 inches = 68½ cubic feet, at 3*s.*	10	5	6
2 middle cill rakers—12 feet long × 12 inches × 12 inches = 24 cubic feet, at 3*s.*	3	12	0
	£111	7	2
			3
	110) 334	1	6
Per yard forward	3	0	9
			5
Carried to Summary. Per length ...	£15	3	9

	£	s.	d.
Timber left in each length for security, or because it cannot be got out:—			
Head trees of top heading—6 in number, each 9 feet 9 long × 9 inches diameter = 24 cubic feet, at 2*s*.	2	8	0
Poling boards—all round arch above top cill level—6 boards 4 feet 6 inches long, and 4 boards 4 feet long = 43 feet × 15 feet = 645 square feet, at 12*s*. per cent.	3	17	5
Bricking-in pieces, 10 per toothing—each 8 feet long × 6 inches × 6 inches = 20 cubic feet at 2*s*.	2	0	0
Iron work, brobs, nails, etc., say ½ cwt., at 16*s*.	0	8	0
Carried to Summary. Per length	£8	13	5

LINING.

Bricks delivered in the Tunnel will not cost less, generally, than 32*s*. 6*d*. per thousand. A 5 yard length, lined 2 feet 3 inches thick, without invert, as has already been stated, contains 86¼ cubic yards brickwork. Bricks being more costly than mortar, in estimating the cost, it will be safe to run the mortar in with the bricks, that is to say, to leave mortar out of the question, and reckon the work as solid brick. A cubic yard of brickwork, if laid without mortar, contains 384 bricks:—

	£	s.	d.
86¼ × 384 = say 33,000 bricks, at 32*s*. 6*d*. = ...	53	12	6
Labour of laying, etc., 86¼, at 5*s*.	21	11	3
Dry brick packings between drawing bars will average about 1 cubic yard per yard forward say 5 cubic yards, at 15*s*. ..	3	15	0
Stick-ups for supporting rib props = 5 cubic yards in mortar, at 18*s*.	4	10	0
N.B.—The labour of building these two latter items is included in the price paid to bricklayers for lining the length.			
Dry rubble packing between brickwork and ground, and in bar holes, will be at least 27 cubic yards per length, with the bars and drop as allowed, 27 at 5*s*. 6*d*.	7	8	6
Carried to Summary. Per length	£90	17	3

	£	s.	d.
Materials required at each face, and which should be sufficient for 110 lineal yards:—			
2 scaffolds at springing level, one standing under length being lined, and the other under last length—5 byats each 26 feet long, 12 inches × 12 inches = 130 cubic feet, at 2*s*. ...	13	0	0
Carried forward	£13	0	0

	£	s.	d.
Brought forward	13	0	0
10 props for do., each ten feet long × 6 inches × 6 inches, Swede timber, 25 cubic feet, at 1*s.* 8*d.*	1	11	8
Planks—3 inches thick, 30 feet × 26 feet = 780 square feet, at 4*d.* per foot	13	0	0
8 half-timbers for setting ribs upon, each 15 feet long, 12 inches × 6 inches = 60 cubic feet, at 2*s.*	6	0	0
12 larch props for supporting ribs, each 8 feet 6 inches long × 9 inches diameter = 45 cubic feet, at 2*s.*	4	10	0
12 pairs hard wood slack blocks, at 1*s.* 6*d.* per pair	0	18	0
4 intermediate ribs, at £6 10*s.* each	26	0	0
[illegible] leading do. at £9 10*s.* each	19	0	0
2 sets laggings, 15 feet long × 7½ inches × 2½ inches, 56 in number 1680 = lineal feet, at 2*d.*	14	0	0
110)	£97	19	8
Per yard		17	10 5
Carried to Summary. Per length	£4	9	[illegible]

SUMMARY.

Cost of a 5 yard length:—

	£	s.	d.
(*a*) Mining and timbering	93	18	6
(*b*) Timber for supporting ground	15	8	9
(*c*) Timber left in	8	18	5
(*d*) Lining, brickwork, and packing	90	17	[illegible]
(*e*) Timber for scaffold, centres, etc.	4	9	2
	£213	[illegible]	0
To this must be added cost of management, such as offices, staff foremen, time-keepers, etc., etc., and contractor's profit, which, together, cannot be set down at less than 20 per cent., say ...	42	12	6
5)	*£255	14	6
Per yard, forward	£51	2	10

* In [illegible] 5 yard length with lining, 2 feet 3 inches thick, bars 2 feet diameter at butt, and 1 foot 6 inches for drop and no invert, there are about 430 cubic yards of excavation; taking items (*a*) (*b*) of Summary and adding 20 per cent. = say £133 ÷ 430 = 6*s.* 2*d.* per cubic yard.

Brickwork in [illegible] similar length = 86¼ cubic yards; taking items (*c*) (*d*) (*e*) of Summary and adding 20 per cent. = say £129 ÷ 86·25 = 30*s.* per cubic yard, nearly.

The cost of sinking shafts is also an addition to this, and these will cost about £6 per lineal yard, in ordinary ground not troubled with much water; suppose the five shafts average 30 yards deep each, it follows that the sum to be added to the cost per yard forward of a Tunnel, one mile long, due to shaft sinking, is about 10*s.*, and centre drain another £1 per yard.

Wear and tear, and depreciation, and interest on purchase of plant, must also be taken into consideration; but it is such an elastic item that it is almost impossible to compute it. However, when the Tunnel is complete, there will be a good deal of material, the cost of which enters into the foregoing estimate, and which will be worth something; it will not, however, cover the wear and tear, etc., of the plant. This will be gathered from the following rough estimate of the plant required:—

	£	*s.*	*d.*
50 tip-waggons, at £10 each	500	0	0
25 horses, at £50 each	1250	0	0
25 sets of harness, at £4 each	100	0	0
3 mortar mills, at £150 each	450	0	0
5 portable engines at shafts, at £210 each	1050	0	0
3 engines for driving mortar mills, at £180	540	0	0
Skips, rallies, trollies, say 40, at £3 each	120	0	0
2 saw benches, at £50	100	0	0
Head gearing of shafts, 5, at £40	200	0	0
5 steam pumps and pipes	750	0	0
Temporary rails, say 50lbs. per yard, say with turn-outs, etc., 2300 lineal yards, single line, 102 tons, at £7 10*s.*	765	0	0
Sleepers, 1 per yard = 2300, at 1*s.* 6*d.*	172	10	0
Fastenings—dogs, 1 ton, at £20	20	0	0
Tools, etc.	200	0	0
Temporary buildings	300	0	0
	£6517	10	0
Depreciation on, say £6500, at 20 per cent. per annum, for two years	2600	0	0
Interest on purchase, at 5 per cent. per annum, for two years	650	0	0
	£3250	0	0

This, together with contingencies, will bring the cost of a Tunnel, in rather heavy ground, as described, to about £58 per lineal yard. The author, however, has had experience of Tunnels costing over £100 per yard, in some parts of which, lining 4 feet thick was required. Bars, averaging 2 feet 6 inches diameter, with an allowance of 3 feet for drop, and with timber such as this, lengths of only 9 feet were possible.

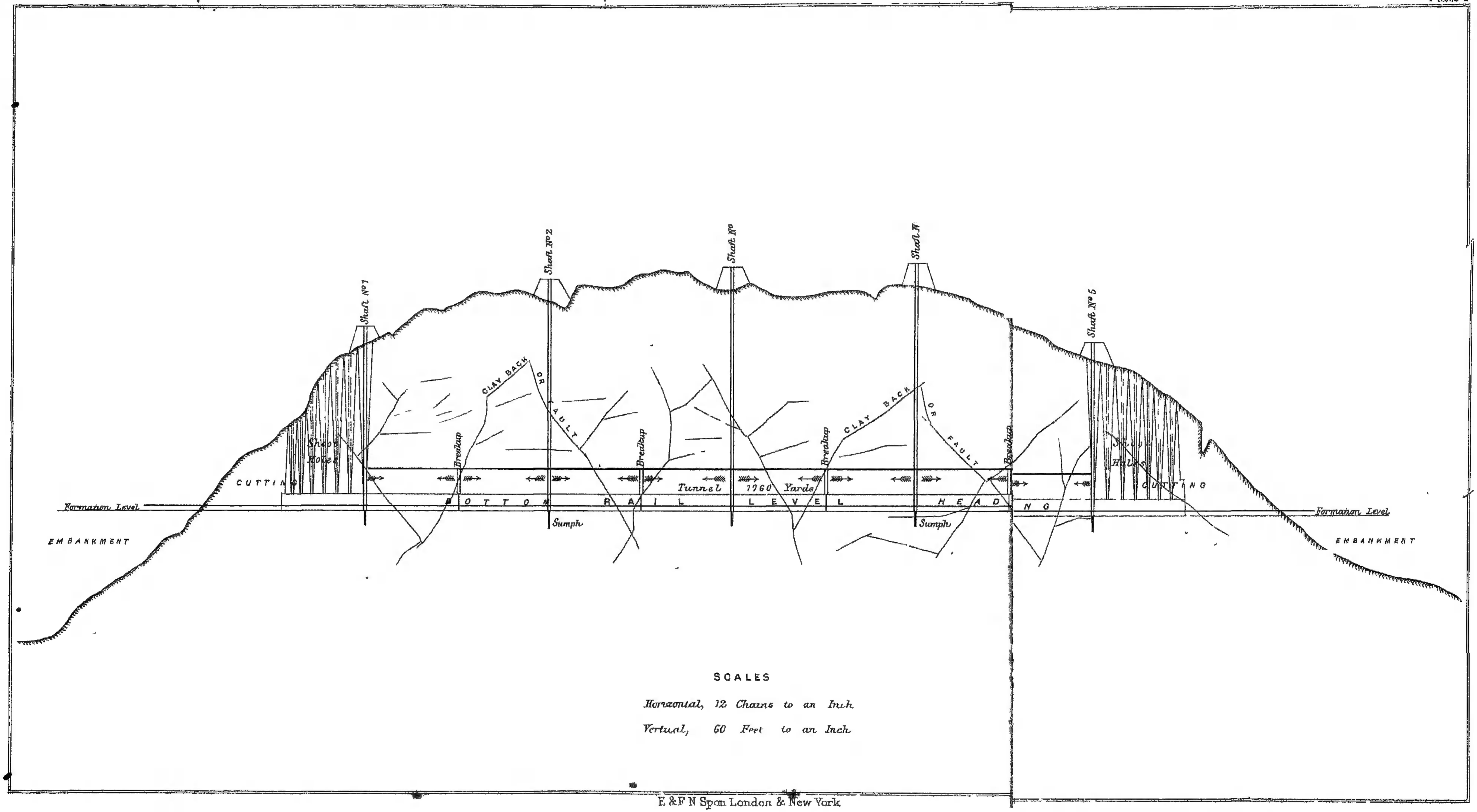
In a wet rock Tunnel, dynamite, or cotton gunpowder, will be found the best explosive, as water is an auxiliary, rather than the reverse, and acts as a tamping. This explosive should not be used, unless the miners have had experience of it before, as its action is altogether different to that of gunpowder, and it is very costly.

For lighting the works of a Tunnel, candles will be found the best and cheapest means, where the work is cramped; each miner has one or two stuck in lumps of damp clay—he can move them about as he pleases, to throw light on his work. When the length gets opened out, naphtha lamps can be used with advantage. Lighting will cost from 1½*d.* to 2*d.* per cube yard excavated.

In bringing this work to a conclusion, the author hopes he has explained the methods of mining, timbering and lining a Tunnel with sufficient clearness, and that, with the help of the diagrams, he will be easily understood by any reader having some little knowledge of Tunnelling, and also sufficiently well, that any one never having had any experience of this class of work, will, after reading this treatise, readily understand what is being, and has to be done when introduced to a Tunnel for the first time; and not be in that humiliating position of having to give, and be asked for, orders upon a subject he knows nothing whatever about.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

Plate 1



E & F N Spon London & New York

Fig. 6.

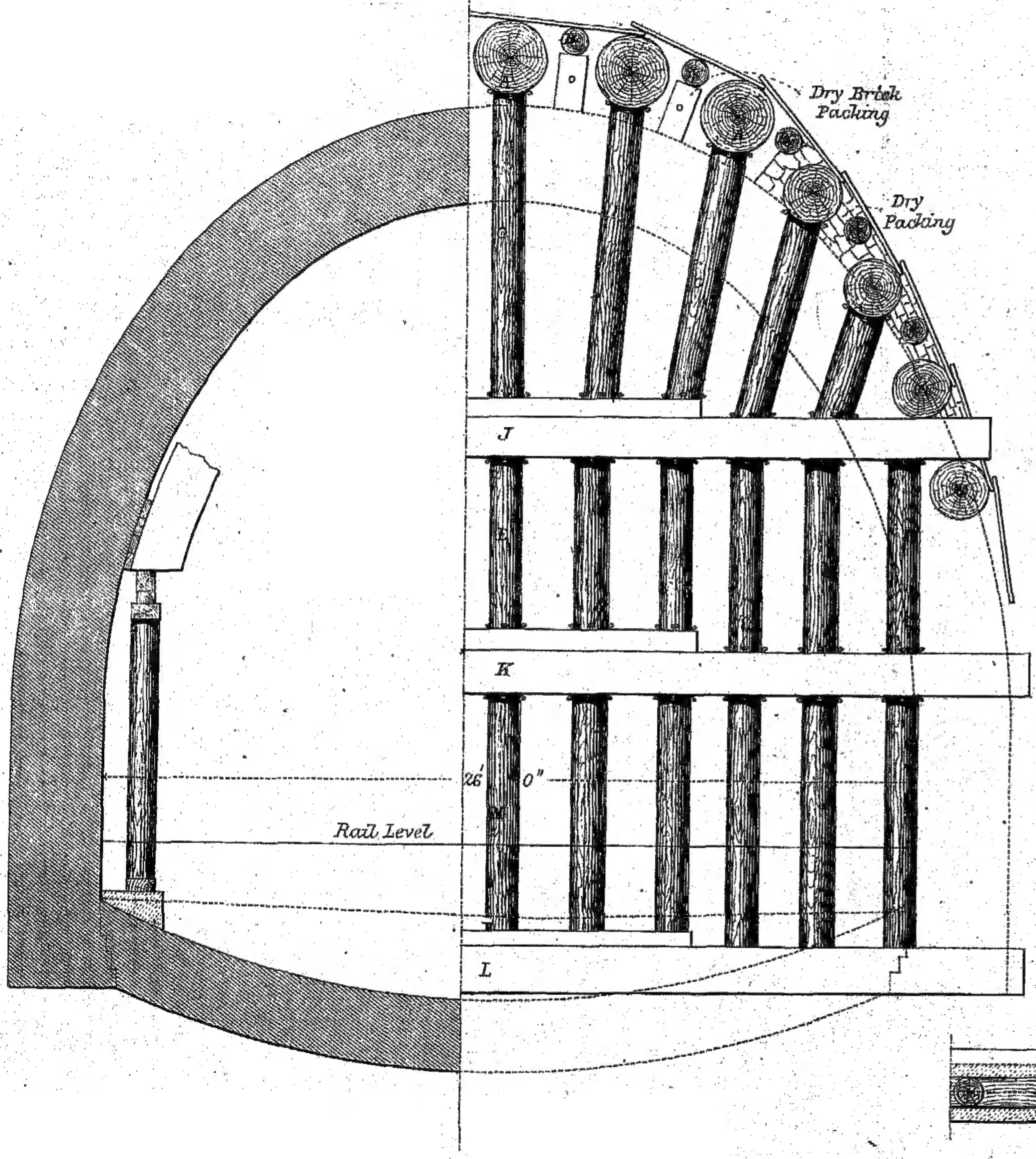


Fig. 8.

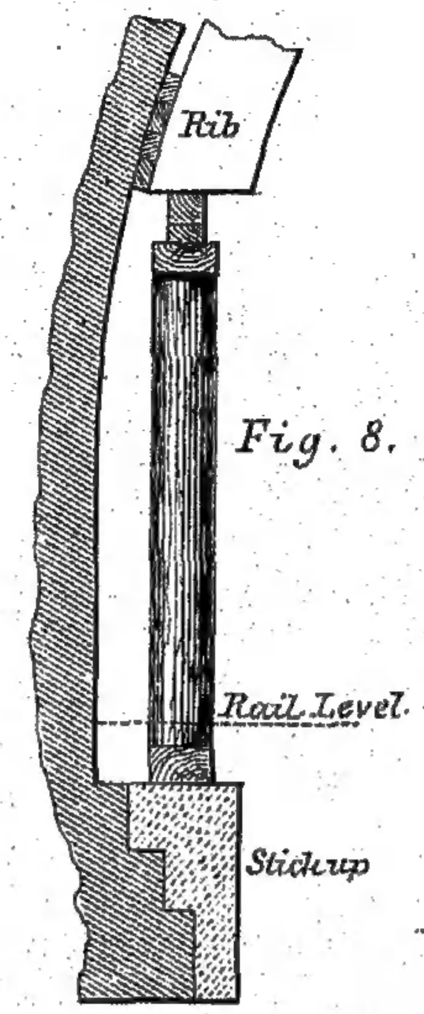


Fig. 7.

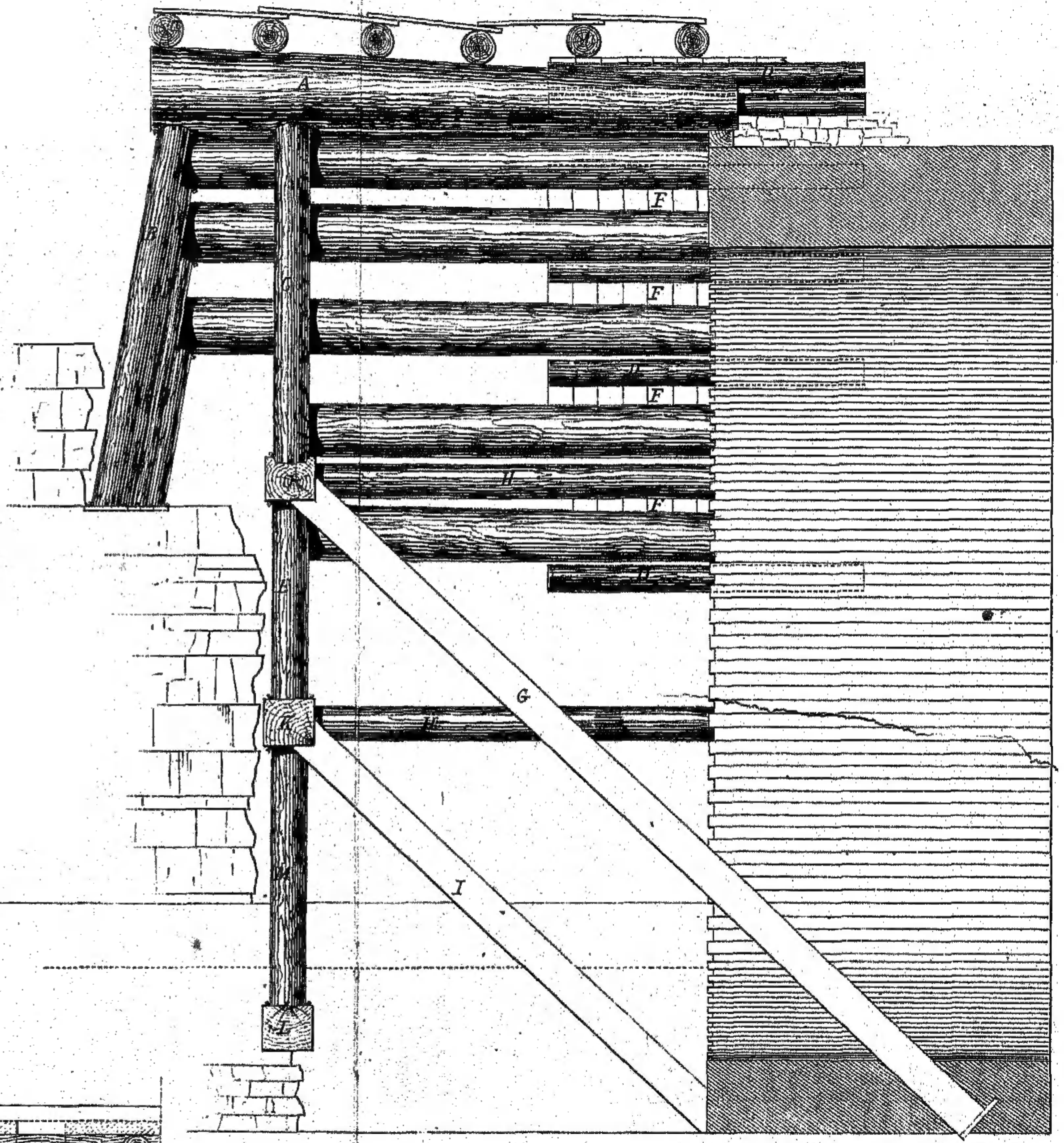
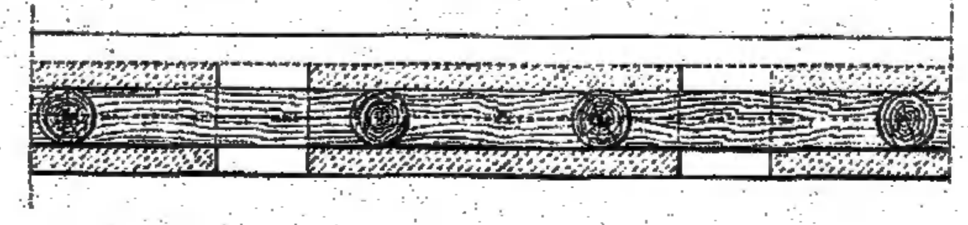
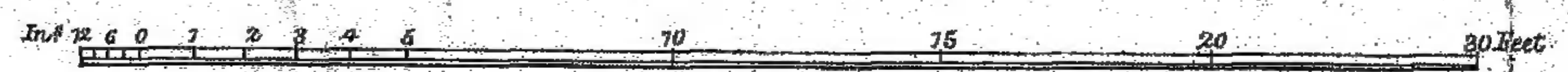


Fig. 8.

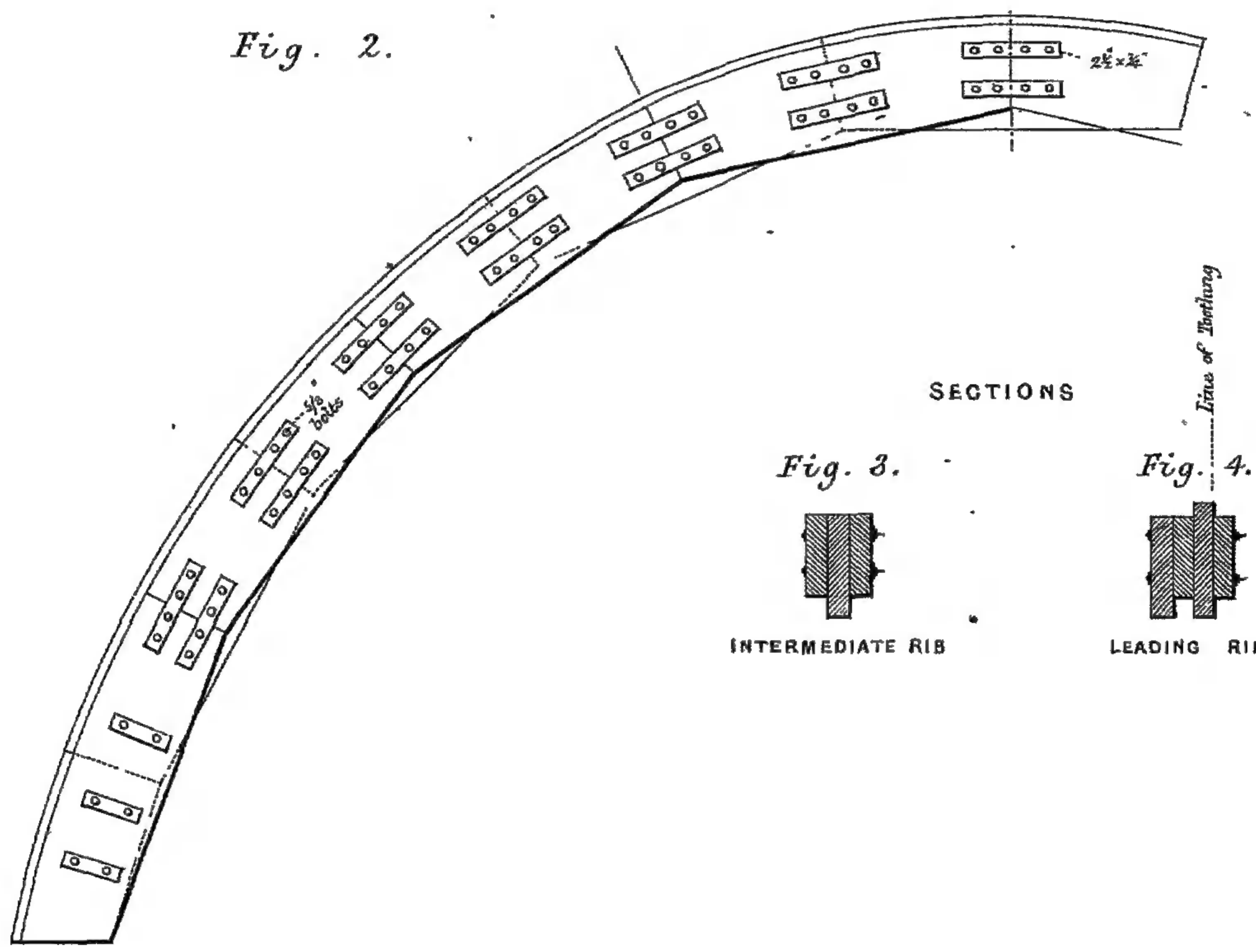




E.&F.N. Spon, London & New York.

HALF TUNNEL ARCH RIB.

Fig. 2.



SECTIONS

Fig. 3.

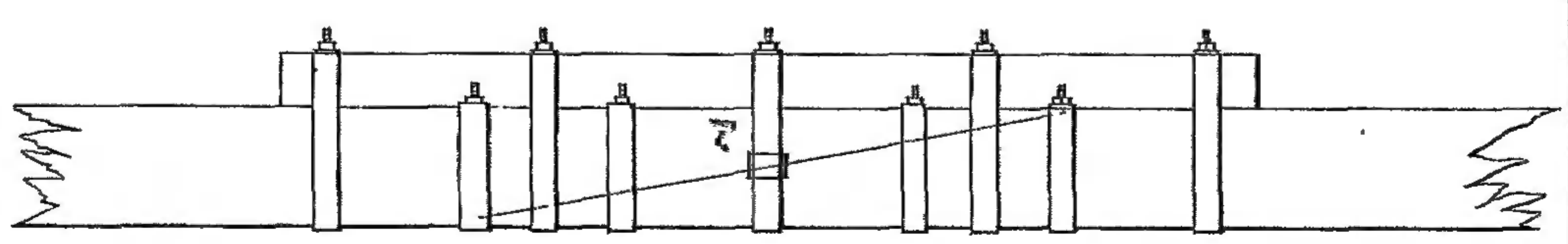
INTERMEDIATE RIB

Fig. 4.

LEADING RIB

Fig. 5.

TUNNEL CILL.



Scale, 3 Feet to 1 Inch.

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